Novel approximated zero forcing pre-coding technique with threshold for diffusion based molecular communication

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Abstract: This letter proposes approximated zero forcing precoding with a threshold in molecular communication (MC). Frequency domain precoding for channel equalization is investigated. Owing to the restriction of a transmitter in MC the main part of an equalized waveform is extracted and a corresponding rectangular waveform is transmitted. In the proposed equalization scheme, the frequency component of the transmit signal is suppressed if a threshold exceeds the channel coefficient in the proposed scheme. Numerical results obtained through computer simulation show that approximation by a single rectangular waveform achieves almost the same performance as that with rectangular approximation that suppresses inter-symbol interference with the proposed precoding technique.

Keywords: molecular communication, precoding, zero forcing, frequency domain equalization

Classification: Wireless Communication Technologies

References

[1] C. Jiang, Y. Chen, and K.J. Liu, “Nanoscale molecular communication networks: a game-theoretic perspective,” EURASIP J. Adv. Signal Process., vol. 5, Dec. 2015. DOI: 10.1186/s13634-014-0188-4
[2] A. Sohail and Y. Sanada, “Novel frequency domain equalization with threshold for molecular communication,” IEICE Commun. Express, vol. 9, no. 2, pp. 36-41, 2020. DOI: 10.1587/comex.2019XBL0143
[3] M. Pierobon and I.F. Akyildiz, Fundamentals of Diffusion-Based Molecular Communication in Nanonetworks, now Publisher. DOI: 10.1561/1300000033
[4] K. Srinivas, A.W. Eckford, and R.S. Adve, “Molecular communication in fluid media: the additive inverse Gaussian noise channel,” IEEE Trans. Inf. Theory, vol. 58, no. 7, pp. 4678–4692, 2012. DOI: 10.1109/TIT.2012.2193554
1 Introduction

Diffusion-based communication through molecules ascends as one of the utmost favorable resolutions for the communication procedure among nano-scale instruments due to its distinctive affinity aimed at alive entities and devices with biochemical procedures, e.g., the propagation of airborne pheromones between insects or calcium signaling amongst active and alive cells whose incredible applications can be achieved in nanomedicine and nano-sensing [1].

One of the problems in molecular communication (MC) is inter-symbol interference (ISI) [2]. In the literature there are various techniques for transmission and reception to overcome the ISI. In [2], noise enhancement due to equalizing a signal with frequency domain equalization (FDE) has been solved by introducing a threshold at a receiver side. In some cases, the more complexity of a system must be covered in a transmitter side. Thus, in this research frequency domain precoding for channel equalization is investigated and thresholding to channel responses is also applied in the proposed system. Due to the restriction of a transmitter in MC the approximation of equalized waveform is also applied. In the proposed scheme, a rectangular waveform that corresponds to the main part of the waveform generated by the precoding is transmitted.

The remaining of this letter is organized as follows. Section 2 describes the system model while the pre-coding method is presented in Section 3. Section 4 provides numerical results and lastly Section 5 concludes the letter.

2 System model

2.1 Molecular communication transmitter

The presumed MC structure model is introduced in [2]. The transmitter produces and releases \(N\) number of molecules through a slit opening into the propagation medium. The transmitter bags the information bits and equalizes the signal in a frequency domain and modulates them to a biochemical signal by a device that produces biochemical particles into a channel. The transmitted molecules are originally dispersed homogeneously throughout the surrounding environment. The particle in the form of molecules is assessed to have low absorption so that the molecules are diffused with a diffusion coefficient, \(D\), into an atmosphere. They diffuse according to Brownian motion and arrive at a receiver [2]. Currently, molecules in the form of tiny droplets of alcohol are assumed. The \(n\)th on-off modulation symbol with a duration, \(T_s\), is denoted with \(s\) as

\[
s = \begin{cases} 
1 & \text{for information bit} = 1 \\
0 & \text{for information bit} = 0.
\end{cases}
\]  

The transmitting pulse has been approximated by an RC parallel equivalent circuit that is given by [3, pp. 20–22]

\[
v_X(t) = se^{-\left(\frac{t}{RC}\right)} \quad t \geq 0
\]

where \(v_X\) is the output voltage level in the form of molecules. The constant resistance value is given as \(R = \frac{1}{D}\) where \(D\) is the diffusion coefficient and the value of \(C = 1\). Since the RC value is large enough as compared to \(t\), the resultant waveform is
almost a rectangular [3, p. 21]. The resulting rectangular waveform has been shown in Fig. 1(a). Due to the restriction in the transmitter, only the amplitude and the duration of the pulse are assumed to be adjustable. The rectangular pulse is a typical type of transmitter pulse waveform as modeled in [3].

![Fig. 1. RC circuit generated rectangular pulse.](image)

### 2.2 Molecular communication channel

The impulse response of a MC channel is characterized as the probable amount of molecules calculated at a specific position owed to constant release by a transmitter that is located at the basis of the coordinate system at time $t = 0$. The diffusion process is represented as Brownian motion and the impulse response of the channel is denoted by $h_X(\tau)$ that is the resultant of conversion from the number of molecules received with a sensor at a delay of $\tau$ to an electrical output through a conversion circuit in the receiver [2] and it is given as

$$h_X(\tau) = N \text{erfc} \left( \frac{d - r_{RX}}{\sqrt{4D\tau}} \right) .$$

(3)

Here $d$ is the distance between the transmitter and the receiver and $r_{RX}$ is the radius of the receiver.

### 2.3 Molecular communication receiver

A single chemical receptor is used to accept information coming after passing through the diffusion process. At the receiving side, the receiver enumerates the incoming molecules by means of a sensor and collects the number of engaged information particles throughout each time-slot [1]. The major challenge for symbol detection is that the molecules arriving the receiver in the last subsequent time slot interfere with those in the current time slot, i.e. symbol-interference, and it corresponds to the symbol interval [4]. The number of engrossed molecules in each time-slot is compared with an adaptive threshold for detection. These particles are distinguished by the receiver that has a radius of $r_{RX}$ and is placed at a distance of $d$ from the center of the transmitter. The probable signal that is received by the receiver is given
by
\[
  r(t) = \int (v_X(\tau) \otimes h_X(\tau))d\tau + n(t)
\]  
(4)

where \( n(t) \) is known as the additive white Gaussian distributed noise (AWGN) and \( \otimes \) denotes convolution [2].

3 Proposed precoding scheme

The precoding reduces ISI through equalization at the transmitter side. The transmit waveform can be equalized in the frequency domain according to the channel response. The ZF coefficient for the \( k \)th frequency component of the transmitted signal is given as

\[
  W_k = \frac{H^*_{sk}}{|H^2_{sk}|}
\]  
(5)

where \( H_{sk} \) is the channel response on the \( k \)th frequency bin and \((\cdot)^*\) denotes the conjugate. In this proposed scheme the pre-coded signal is compared with a pre-selected threshold and the frequency elements after equalization is set to zero if the channel response is less than the selected threshold. This is because only low frequency components tend to pass through the MC channel [2]. After that the main part of the signal is approximated to a rectangular waveform since only the rectangular waveform can be generated at the transmitter. The process for selecting coefficients is represented as

\[
  A_k = \begin{cases} 
    0 & \text{for } H_{sk} < T_h \\
    W_k s_k & \text{for } H_{sk} > T_h 
  \end{cases}
\]  
(6)

where \( T_h \) is the preselected threshold value that is set for the normalized channel impulse response and it is less than and equal to 1.0. \( s_k \) is the on-off modulation symbol on the \( k \)th frequency bin that has been defined in Eq. (1).

The waveform of one symbol duration is presented in Fig. 2(a). The “Original” depicts the equalized signal without the threshold. Due to the MC transmitter design limitation that is described in terms of RC circuits in [3, pp. 20–21] the appropriate technique to approximate the equalized signal in a rectangular waveform is required. Afterwards the signal waveform that exceeds the zero level is approximated by the rectangular pulses with the durations that is the same as the durations of positive part of the waveform; In Fig. 2(a), this waveform is presented as “Rect Wave”. The approximated rectangular waveform for only the main part of the waveform that contains the maximum amplitude is selected to be transmitted as it inhabits the main part of the energy is depicted by “Main-Rect Wave”. Fig. 2(b) represents the channel impulse response (CIR) in frequency domain of MC. The Main-Rect Wave is then multiplied by the CIR in frequency domain to formulate the received signal.

The signal received at the receiver in the frequency domain is shown in Fig. 2(c). The same impulse responses of a MC channel as those in [2] are assumed and it implies that the MC channel mainly passes low frequency components. Because of the restriction of the MC transmitter design, for one-bit transmission with the rectangular pulse waveform, the leading method in this regard is to select the main part for approximation. “NO-TH” represents the performance with \( Th = 0 \) while the
range of other thresholds are varied from zero to 2.0. It is clear from Fig. 2(c) that the largest amount of energy passes through the MC channel for a threshold value of 1.0.

4 Numerical results

4.1 Simulation conditions

For the purpose of numerical evaluation through computer simulation the following simulation conditions are assumed; 1 million symbols are transmitted for each plot and the diffusion coefficient of alcohol is $D = 9.59 \times 10^{-6}$ m$^2$/s. The radius of the receiver is $r_{RX} = 1 \mu m$ and the distance between the transmitter and the receiver is $d = 5 \mu m$. The total number of molecules transmitted are $N = 10^3$. The size of the FFT is $M = 200$. The normalized threshold for ZF precoding is set to 1.0. $E_b$ is the bit energy while $N_0$ is the noise spectrum density derived through the variation of outputs of the conversion circuit that converts the number of received molecules to the electrical signal. The interval of 1 symbol duration is taken as 1 sec, while for the end to end system performance symbol interval, $T_s$ is taken as 0.5 sec in the simulation indicating that ISI occurs when half of the symbols overlap [2].

4.2 Performance results

The bit-error-rate (BER) performance for different thresholds is presented in Fig. 3(a). Here threshold has been varied from zero to 2.0. It has been clearly
visible that the best performance is depicted by taking threshold value of 1.0 i.e. TH 1.0.

The BER performance versus bit-energy-to-noise-spectrum-density ($E_b/N_0$) for different systems is presented in Fig. 3(b). At an $E_b/N_0$ of 14 dB, it’s been obviously visible that precoding with the threshold, i.e. “Original,” realizes the better system performance while the transmitter that combines precoding and rectangular wave signal approximation, i.e. “Rect Wave,” shows the worst performance. Furthermore, it is clear that the proposed system of incorporating ZF precoding with the threshold with rectangular approximation for the main part of the waveform, i.e. “Main-Rect Wave” shows the almost equivalent performance as compared to “Original Wave”.

5 Conclusions

This letter proposes zero forcing precoding with a threshold to achieve better system performance for the diffusion based MC. According to the nature of nanotechnology, the MC receiver has to be simple for many grounds like the price and the size of the receiver unit. Therefore, the transmitter, base station, will apply precoding with the threshold and forecasts the channel for the better end to end MC signal communication. It has been shown in the above sections that the frequency components that are concentrated at around zero frequency components that pass through the MC channel. Applying the threshold improves the system performance. The conventional precoding with rectangular wave approximation for a threshold value of zero shows the worst performance because of the presence of ISI. On the other hand, it is clear that the proposed scheme achieves better performance for a threshold value of 1.0. The approximated rectangular waveform for only the main part of the original waveform that contains the maximum amplitude and this approximated precoding achieves comparable equivalent performance with the original waveform.