Impulse response

Results

Conclusions

References

Discussions

Method A: Channel Inversion

Method B: Design Window Function

Abstract

This paper presents a method for shaping the transmit pulse of a molecular signal such that the diffusion channel's response is a sharp pulse. The impulse response of a diffusion channel is typically characterized as having an infinitely long transient response. This can cause severe inter-symbol-interference, and reduce the achievable reliable bit rate. We achieve the desired chemical channel response by poisoning the channel with a secondary compound, such that it chemically cancels aspects of the primary information signal. We use two independent methods to show that the chemical channel response should be \( \propto \left( \frac{-t}{D} \right)^{\frac{3}{2}} \) and that the poison signal should be \( \propto \left( \frac{-t}{D} \right)^{\frac{1}{2}} \).

Background

Molecular communications using nano-sized chemical particles is interesting to the field of biology and telecommunications. In terms of both nature and engineering, the communications challenge is that the local environment is often hostile to the utilization of radio-frequency (RF) systems. It has been shown in the last few years that chemical particles can be a viable carrier for information and they offer unique advantages and challenges [1]. One of the challenges that the characteristic channel response is an infinitely long transient response (2, 3, 4). Therefore, the excess interference caused by a train of chemical pulses will build up at the receiver and cause significant bit errors.

Pulse Shaping Formulation

Let us consider an on-off-keying binary encoded system, where by a semi-infinite channel separates a chemical transmitter and a receiver. As shown in [1, 5], subject to

\[
\phi (x, t) = \exp \left( \frac{x}{2 \sqrt{D} t} \right),
\]

where \( x \) is the distance separating the transmitter and the receiver, and \( D \) is the diffusivity. Eq. (1) is the cumulative function of the captured molecules, which monotonically increases with time \( t \). To obtain the instantaneous number of molecules captured (impulse response \( h(t) \)), we differentiate Eq. (1) with respect to \( t \):

\[
h(t) = \frac{\partial \phi (x, t)}{\partial t} = - \frac{x}{2 \sqrt{D}} \phi (x, t) - \exp \left( - \frac{x}{2 \sqrt{D}} t \right).
\]

We further note that the pulse shape derived using the windowing method in Eq. (7) is:

\[
x(t) = \frac{1}{\sqrt{2 \pi}} \exp \left( \frac{-t^2}{2} \right).
\]

The composite transmit pulse derived in Eq. (4) has a positive element \( (T > 0) \) and a negative poison element \( (T < 0) \). Let \( \phi(t) \) be the information signal (compound A), and the \( \propto t^{\frac{3}{2}} \) term be the poison signal (compound B) which can cancel out aspects of compound A’s impulse response.

We consider inverting the channel in the complex s-domain. Let us consider a desired received pulse shape that is a sharp pulse \( \psi(t) \). Therefore, the desirable composite input signal is:

\[
x_d(t) = \frac{\psi(t)}{h(t)} \exp \left( \frac{x^2}{2 \sqrt{D}} \right),
\]

for \( \psi(t) = 1 \). If we consider a transmission system, where the distance is much smaller than the diffusivity rate \( (x < \sqrt{D}T)^2 \). Series expansion can be employed \( ( \exp(u) = 1 + u + \ldots ) \). Inverse Laplace transform yields two terms \( ^h \Xi = \frac{1}{\sqrt{4 \pi t}} \) and \( ^p \Xi = \frac{1}{\sqrt{4 \pi t}} \) erfc \( \left( \frac{x}{\sqrt{4 \pi D t}} \right) \). Therefore, the composite signal is:

\[
x(t) = \frac{x^2}{\sqrt{D}} \Xi \left( \frac{x}{\sqrt{D t}} \right) = \frac{x^2}{\sqrt{D}} \Xi \left( \frac{-t}{\sqrt{D}} \right).
\]

In order to find the desired poison pulse at the transmitter, we de-convolute \( \psi(t) \) with the channel:

\[
\Psi_1(t) = \frac{\psi(t)}{h(t)} \exp \left( \frac{x^2}{2 \sqrt{D}} \right) \Xi \left( \frac{x}{\sqrt{D t}} \right) \Xi \left( \frac{-t}{\sqrt{D}} \right).
\]

We further note that the pulse shape derived using the windowing method in Eq. (7) is a scaled version of that derived via the channel inversion method in Eq. (4).

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We further note that the pulse shape derived using the windowing method in Eq. (7) is a scaled version of that derived via the channel inversion method in Eq. (4). We further note that the pulse shape derived using the windowing method in Eq. (7) is a scaled version of that derived via the channel inversion method in Eq. (4). In verifying our results, Fig. 1 shows the simulated system response with additive noise. Clearly the poisoned system response will yield fewer errors and be able to achieve a higher reliable data rate. The pulse shapes derived are valid for all microscopic or high diffusivity chemical channels.

\[ \text{References} \]


\[ \text{Discussion} \]

The composite transmit pulse derived in both Eq. (4) and Eq. (7) have a positive information element \( (T > 0) \) and a negative poison element that is continuously emitted \( (T > 0) \).

We further note that the pulse shape derived using the windowing method in Eq. (7) is a scaled version of that derived via the channel inversion method in Eq. (4).

In verifying our results, Fig. 1 shows the simulated system response with additive noise. Clearly the poisoned system response will yield fewer errors and be able to achieve a higher reliable data rate. The pulse shapes derived are valid for all microscopic or high diffusivity chemical channels.

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