Microchannel Molecular Communication with Nanoscale Carriers: Brownian Motion versus Active Transport

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Summary

- In molecular communication [1] information is conveyed by encoding messages into the timing or identities of molecules, which are released by a transmitter and propagate to a receiver.
- Molecules are transported from a transmitter passively (Brownian motion) or actively (molecular motors) [2,3] to a receiver.
- In this work, the achievable information rates of Brownian motion transportation is compared with the achievable information rates of active transport using molecular motors.
- The environment considered is a rectangular channel with strip loading (transmitter) and unloading (receiver) zones. We assume that information is encoded in the number of vesicles/particles.
- Based on our results when the number of vesicles/particles are low, active transport using molecular motors achieve higher information rates. However, for large number of vesicles/particles Brownian motion achieves higher information rates.

Information Transmission Rates

We assume that the vesicles themselves are not information-bearing, and a message is conveyed in the number of vesicles arranged on the microtubules. For example, if a maximum of three vesicles may be used, we may form message words bits long (e.g., "00" for 0 vesicles, "01" for 1 vesicle, "10" for 2 vesicles, and "11" for 3 vesicles). However, this message is not perfectly conveyed to the receiver; given a time limit T for the communication session, it is possible that some of the vesicles will not arrive at the unloading zone after T has elapsed.

Let x represent the random number of vesicles present at the loading zone, and y represent the number that arrive at the unloading zone once T seconds have elapsed. We are interested in the Shannon mutual information I(X;Y), given by

\[ I(X;Y) = \sum f(x)f(y) \log \left( \frac{f(x)f(y)}{f(x)f(y)} \right) \]

where, in this example, f(x) represents the probability of observing x vesicles at the unloading zone, given that x were released and f(y) represents the probability of releasing y vesicles at the loading zone. The value of I(X;Y) represents the maximum rate at which data can be reliably sent over the link, measured in bits per time T. To calculate the value of I(X;Y), the function f(x) is obtained by simulating the motion of vesicles/particles in T seconds many times.

Results

![Figure 3](image)

Figure 3. (LEFT) Histogram of the number of vesicles transported by a single microtubule in time T = 64.67 min. (RIGHT) Mutual information versus number of microtubules. The distribution of f(x) is uniform over {0, 1, ..., xmax}. For most values, a maximum occurs because the number of vesicles that can be transported is limited.

![Figure 4](image)

Figure 4. (LEFT) Mutual information versus number of microtubules. The distribution of f(x) is uniform over {0, 1, ..., xmax} and f(y) is chosen to maximize mutual information. (RIGHT) A plot comparing mutual information of a single microtubule to Brownian motion, plotted with respect to the source entropy log (xmax+1) (bits per bits at source).

- Mutual information increases as xmax increase and reaches a maximum peak for active transport because the transfer of mass is limited by the number of available microtubules. However, for Brownian motion mutual information is always increasing. (Figure 3 Right).
- Mutual information increases significantly as the number of microtubules increases, since it is possible to transport additional vesicles. However, the increase in mutual information is only logarithmic in the number of microtubules, so greater relative improvement is expected for small numbers of microtubules. (Figure 4 Left).
- We see a large advantage in using molecular motors when the maximum number of available vesicles (i.e., xmax) is small. However, for larger values of xmax Brownian motion achieves higher rates than molecular motors (Figure 4 Right).

References


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