A Molecular Communication Model Driven by Magnetic Field Force

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Abstract. Molecular communication is a novel method of communication that utilises nano-engineering and bio-engineering to enable temporary communication in harsh environments. As nano-technology and bio-engineering continue to advance, the feasibility of molecular communication is constantly improving. This paper examines the feasibility of using magnetic nanomaterials as information carriers for medium-distance transmission driven by magnetic field force, based on the existing molecular communication theory of diffuse channel. The study compares the two situations with and without relay. After conducting derivation and simulation verification, it can be concluded that the transmission rate and bit error rate data results are excellent when under the influence of magnetic field force drive. Additionally, the molecular communication system with relay is significantly more effective than the system without relay.

Keywords: molecular communication · Communication system · nanomaterials · Magnetic field · modulation

1 Introduce

1.1 Motivation

Currently, optical and electromagnetic communication provide significant convenience to daily life, and each technological innovation brings about substantial changes. However, mainstream communication methods rely heavily on a stable electromagnetic communication environment and perform inadequately in certain environments, such as underwater, battlefield, mountain tunnels, and metal spaces [1]. Scientists have been exploring new methods of communication that can function in extreme environments. As a result, molecular communication

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has gained increasing attention from researchers and has been extensively developed, leading to the derivation of numerous scientific theories. Scientists learn from nature's experiences and simulate various physical and chemical effects of organisms. They use micro-robots or nanomaterials to carry or act as signal molecules and design a communication system based on nanomachines to transmit information between the sending, relay, and receiving ends.

The concept of molecular communication has attracted the attention of many scientists since its inception. Numerous scholars and enterprises, both domestic and international, have invested in researching molecular communication. Additionally, many relevant institutions worldwide have been established to conduct research. Molecular communication has significant development prospects due to its integration of various high-tech fields, including nanotechnology, computer technology, communication technology, and physical and chemical technology. Molecular communication has significant development prospects due to its integration of various high-tech fields, including nanotechnology, computer technology, communication technology, and physical and chemical technology. Therefore, researchers also need address unknown problems in this field.

In recent years, there has been significant progress in the development of nano-micro machines, which has greatly aided the feasibility of molecular communication. Nanomachines are currently being widely used in various fields, including biomedicine, human equipment, and industrial monitoring. Therefore, it is evident that the use of nanomachines as a carrier for information transmission has excellent potential for application, editing, and feasibility, and is naturally resistant to interference.

1.2 Related Works

The molecular communication system has a structure similar to the traditional communication system, which is composed of transmitter, channel and receiver [2]. The communication process involves the transmitter encoding or modulating the source information and then releasing the corresponding signal particle type and number. The signal particles travel through the channel to the receiver or relay. This trunk is identified and detected, and then transmitted to the next trunk. The receiver performs recognition and detection, and then performs demodulation decoding to restore the original transmitted information. At present, molecular communication technology is widely used in environmental detection, medical care, industry and other fields.

(1) Medical care
Molecular communications are often used in conjunction with drugs in healthcare and various nanoscale detection devices, enhancing their capabilities and providing an alternative solution for more comprehensive and stable medical data reporting. In the detection of various indicators of the human body, sweat, blood and other body fluids are often used as transmission channels to detect and identify drug signaling molecules. This can provide multiple data test results, collect diagnostic information, and help

detect hidden lesions in advance. Molecular communication not only provides solutions to save patients, but also provides mechanisms for disease prevention. Molecular communication can be combined with targeted drug technology to achieve precision therapy [3]. Drug molecules are typically encapsulated in a carrier and then delivered to the target cell through the body's internal fluid circulation, releasing the drug molecules for targeted therapy while reducing toxic effects on non-targeted cells. Molecular communication technology can meet the carrier's function of identifying target cells and delivering drugs, and carry drug molecules to target cells for precise delivery through nanomachines, which greatly improves the accuracy and therapeutic performance of targeted drugs. Molecular communication is frequently employed in the healthcare industry for molecular imaging to locate diseased tissue more quickly and accurately. For instance, the signal molecule green fluorescent protein (GFP) can be utilised. When GFP is transported through cells and enters the human body, molecular communication technology will target the carrier around the affected cell. Subsequently, the fluorescence imaging equipment in vitro will illuminate the position of the diseased tissue [4].

(2) Environmental testing
Molecular communication technology can be a valuable tool in detecting environmental pollution sources. To cover a detection area, a nanosensor network can be deployed in advance and equipped with nanomachines capable of detecting pollutants. The nanosensors will continuously monitor the pollutant molecules. Once the target pollutant molecules are detected, the nanonetwork will upload the data report and release degradation substances to prevent further spread of pollutants. To achieve simple prevention and treatment of environmental pollution, it is important to identify the source of pollutants based on their concentration. Additionally, the construction of a comprehensive nano sensor network can facilitate cooperation between nano machines.

(3) Engineering application
Buildings require long-term monitoring and maintenance to prevent sudden structural damage that can endanger people's lives, health, and property. Nanomaterials, including nanosensors, are being used for small deformation detection on building surfaces. This allows for real-time and continuous monitoring. When the building begins to show signs of deformation, the nanosensor detects the data and uploads it to the safety control network center. This allows for real-time monitoring of any risks present in the building and also warns of any potential large deformations in the building structure, thereby reducing personnel safety risks and production costs [5].

2 Diffusion Channel Molecular Communication Model Driven by Magnetic Force

2.1 Modeling of Magnetic Force

In a closed space unaffected by external physical and chemical conditions, three electrified helical coils are distributed axially for simple analysis. In fact, we are utilising point-to-point communication, whereby the magnetic force automatically propels the signal molecules to move, even in the absence of axial distribution of multiple sites. The axial effect can be achieved. The electrified size and direction are the same, forming a magnetic field between them, as shown in Fig. 1.

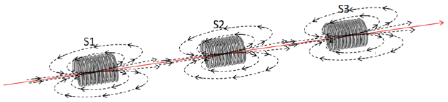

Fig. 1. Electrified helical coil is distributed axially

As the magnetic field force is a vector, various factors such as the material, winding method, and current size of different helices will have an impact. In consideration of the communication distance and the dimensions of the signal molecules, we simplify the analytical model. we abstract the current helices in the magnetic field model into magnetic charges for analysis. The formation of an equipotential sphere is a consequence of the distribution of the magnetic field in space. The magnetic charge represents the distribution of the model in space, and thus ignores the influence of the shape and volume of the model. This is analogous to the electric field formed by a point charge in the surrounding space. The magnetic charges are represented by S1, S2, and S3 stations from left to right, as shown in Fig. 2. This article only takes three sites as examples, that is, from S1 through S2 to S3.

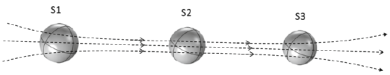

Fig. 2. Spherical magnetic charge model

During molecular communication, magnetic nanomaterials are transmitted from the sending end S1)to the receiving end S2. At the start of the communication process, S1 releases magnetic nanomaterials as signal molecules with an initial velocity of 0. At this point, only S2 is powered on, while the other sites remain powered off. This creates a magnetic field distribution in space with S2 as the magnetic charge. Magnetic nanomaterials are transferred from S1 to S2 using magnetic forces. Then, this process is repeated again. During the transfer from S2 to S3, only S3 is powered on while the other stations are powered off. This creates a magnetic field distribution with S3 as the magnetic charge, attracting magnetic nanomaterials for detection, identification, and decoding. The signal molecule is propelled by the magnetic force through the relay point to the target receiver. The final receiver within a certain range can be detected and decoded. Eq. (1) expresses the force of magnetic nanomaterials in the magnetic field, according to existing theory.

$$F = \frac{q_1 q_2}{4\pi\mu_0 r^2} \tag{1}$$

From classical mechanics, we know that F=ma and a is acceleration. The time it takes to move from one end of two stations to the other under the action of magnetic field force can be calculated using Eq. (2), where q1 and q2 represent the magnetic charge carried by each site, 0 is the vacuum permeability, and r is the distance between the two sites.

$$t = \sqrt{\frac{8\pi\mu_0 m r^3}{9 q_1 q_2}} \tag{2}$$

Assuming the mass of the three magnetic nanomaterials A, B, and C is 'm' and defining the magnetic charge to mass ratio of all three as 1 for convenience of calculation. Molecular type modulation and concentration modulation are used, where the sender releases n quantities of A, B, and C, representing 111. Similarly, n quantities of B and C represent 011, and when nothing is sent, 000 is transmitted.

2.2 Molecular Communication Diffusion Channel Analysis

Previous studies have shown that the motion of signaling molecules in diffusion channels can be analyzed using Wiener processes, also known as Brownian motion processes. The physical model of the Brownian motion of the signal molecule released from the transmitter in the channel can be described by the Gaussian distribution, as shown in Eq. (3) [6].

$$x \sim N\left(n, \sigma^2\right) \tag{3}$$

If a single messenger molecule is released at t = 0, and after time t, the distance between the messenger molecule and the origin is expressed by x, its probability is Eq. (4).

$$P\left(x, t\right) = \frac{1}{\sqrt{\left(4\pi D t\right)^3}} exp^{-\frac{x^2}{4Dt}} \tag{4}$$

Among this these variables, D represents the free diffusion coefficient of the enabling molecule for a given diffusion channel, t represents the time elapsed through Brownian motion, and x represents both the drift and detection range at the receiving end. A larger value of x indicates a larger detection range for signal particles at the receiving end [7].

In a given time slot, the particle transmitter releases n signal particles into the channel. As the movement of these particles is relatively independent, the number of particles received by the receiver in the same time slot follows a binomial distribution. In the large number theorem, if the number of particles n is sufficiently large that the motions between each particle are relatively independent and conform to the binomial distribution, then the binomial distribution can be substituted with a Gaussian distribution,$N_r$represents the n molecules that reach the receiving end and are absorbed.

$$N_r \sim N(np(x,t), np(x,t)(1-p(x,t)) \tag{5}$$

In the diffusion channel, ISI is the main source of noise interference in the molecular communication system. This interference is caused by unabsorbed signal particles from the previous time slot remaining in the channel during the continuous time slot. As a result, these signal particles fail to reach the receiving end in their own time slot but are instead mixed with the signal particles in other time slots. ISI is generated when the receiving end receives an abnormal number of signal particles in other time slots. The number of signal particles received in the current time slot is related not only to the number of signal particles released by the sender of the current time slot, but also to the number of signal particles released by all previous time slots, as previously derived. Assuming that the sending end releases n signal particles each time, and N_{it} represents the number of messenger molecules released by the first i time slot of the current time slot are absorbed in the current time slot [8], that is, the number of molecules absorbed by the receiving end after i×ts time:

$$\begin{aligned} N_{it} \sim \frac{1}{m}\{N(np(x,(i+1)t), np(x,(i+1)t)(1-p(x,(i+1)t)) - N(\\ np(x,it), np(x,it)(1-p(x,it))\} \end{aligned} \tag{6}$$

where $i \geq 2$, m represents the number of molecular types used in the modulation method.

The ISI is determined by the number of signal particles remaining in all previous time slots. This calculation and simulation process can be complex. However, the interference caused by signal particles from time slots that are far away and require a large amount of calculation can be ignored [9]. Therefore, we consider only the k time slots before the current one. A larger k implies more interference from signal particles of the previous time slots. For instance, when k = 4, the current time slot is affected by ISI caused by residual signal particles from the previous four time slots [10]. Therefore, when the transmitter releases n signal particles after a time slot, the number of particles currently received within a certain detection range at the receiving end can be deduced, in combination with the above deduction.

$$\begin{aligned} N_A &\sim N_r + N_{it} \\ &= N(np(x,t), np(x,t)(1-p(x,t)) + \frac{1}{4}\sum_{i\geq 2}^{k}\{N(np(x,(i+1)t), \\ &np(x,(i+1)t)(1-p(x,(i+1)t)) - N(np(x,it), np(x,it)(1-p(x,it))\} \end{aligned} \tag{7}$$

2.3 BER and Simulation Analysis

The calculation of the bit error rate for a molecular communication system using the maximum decision criterion in Bayesian detection involves the following steps, according to existing theory: Represent the total number of messenger molecules received by the receiving end in a time slot with G. There are two hypotheses, as shown in the following formula:

$$H_0 : G = N_0 \sim \left(\mu_0, \sigma_0^2\right) \tag{8}$$

$$H_1 : G = N_1 \sim \left(\mu_1, \sigma_1^2\right) \tag{9}$$

where, N0 represents the total number of signal molecules received by the receiving end and judged as bit "0", N1 represents the total number of signal molecules received by the receiving end and judged as bit "1", and table G of N0 and N1 respectively follow Gaussian distribution [11].

The distance between any two stations is 10 m, the distance from S1 to S2 is 10 m and the distance from S2 to S3 is also 10 m. When the electricity is started, a magnetic field in the direction from S1 to S3 is formed in the space, and the nanomagnetic material moves from the S1 to the S3 as a signal molecule. The receiver has a detection range of a sphere space with a radius of 0.5 m. The magnetic charge of the station is 10M/A. The relay station only detects particles and does not affect their motion. The detection of the signal molecule by the relay is instantaneous, and the initial speed of the signal molecule becomes 0 after the relay. The system does not take into account particle collisions or spatial drag. The switches between each site are synchronized, and the bit error rate is calculated using the maximum a posteriori criterion.

Figure 3 shows that considering more time slots has a slight effect on the bit error rate caused by the interference of signal particles. Therefore, it is not necessary to completely eliminate the influence of ISI when designing molecular communication systems [12].

We set k to 2, change the particle detection range of the receiving end from 0.5 m to 2 m, and detect once every 0.5 m to compare the bit error rate under different detection ranges. The data results are shown in Fig. 4. The larger the detection range of the receiver, the lower the bit error rate.

Assuming a station length of 10 m, particles with relay have a total arrival time of 0.3746 s, while particles without relay have a total arrival time of 0.5298 s. Figure 5 shows a comparison of the BER between the two cases. The use of a relay in molecular communication systems significantly reduces the BER.

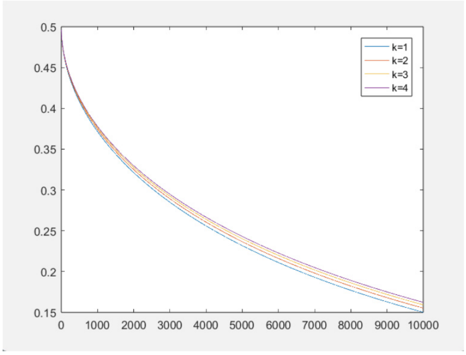

Fig. 3. Influence of different number of time slots on bit error rate

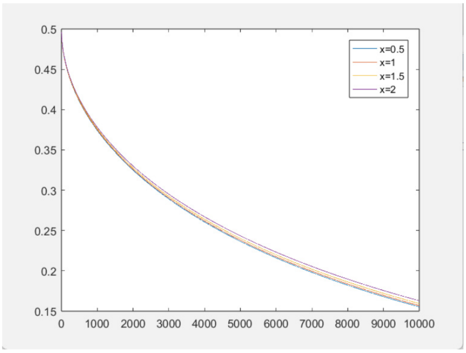

Fig. 4. BER under different detection range

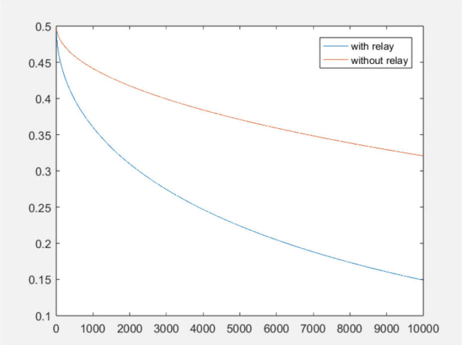

Fig. 5. with or without relay error rate comparison

3 Conclusion

In the magnetic field-driven molecular communication system, we compared the BER of two communication systems: one with relays and one without relays. Our results demonstrate that the relayed system has a significantly lower BER in the magnetic field environment compared to the non-relayed communication system. This paper examines the diffusion channel solely under the influence of ideal magnetic force. It is important to note that the results may differ when combined with actual data. The following issues require further attention:

1. In molecular communication, multiple relay points can be used to improve the speed and accuracy of communication. However, the optimal number of relays for a given distance between the sender and receiver is still an area of study.
2. Multiple relay points require precise synchronization of power supply timing and duration to achieve the best communication effect. To prevent excessive Brownian motion of signal molecules during molecular communication, a compensation mechanism can be added during relay detection to account for the loss of signal molecules passing through the relay and ensure they reach the detection range of the next relay.

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