A Method for Determining Relay Node Location in Molecular Communication

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Abstract. In the scenario of molecular communication, targeted drug delivery is usually used for the treatment of tumor cells because of its low consumption point with few side effects. Therefore, drug-carrying nanomachines are important for targeted delivery to tumor cells. In this paper, a method optimizing the location of relay nodes on the basis of the relaying method is proposed, which results in a shorter transportation path. There are two types of nanomachines, relay nanomachines aim to form relay nodes in a straight line from the base to the destination and delivery nanomachines to carry drugs. This method first forms an optimal region and then determines the optimal position. Parameters such as the number of nanomachines and the number of attractants in the system were then analyzed and discussed.

Keywords: molecular communication · relay node · cancer therapy

1 Introduction

The concept of molecular communication was first introduced in 2005 [1], which uses biochemical signals to enable communication between nanosystems. In a biological environment, many nanomachines assembled together to form a nanonetwork can perform some medical tasks such as anomaly detection and targeted drug delivery. In the literature [2], it is stated that nanomachines provide new ideas and solutions in the biomedical field.

Cancer has always been a major concern in the medical community, and the mortality rate of cancer cells is much higher if they spread to healthy parts of the body. Chemotherapy is short for chemotherapy, which is one of the common means of treating cancer by delivering chemotherapeutic drugs to the affected area orally or intravenously to kill cancer cells. However, the drugs may also act

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on normal cells, which not only reduces the utilization rate of the drugs but also causes damage to normal cells.

Targeting drug delivery (TDD) is a method of controlled, targeted delivery of drug-carrying nanoparticles to a diseased area of the body, with the aim of protecting healthy areas and reducing the breakdown and loss of the drug, thereby improving the use of the drug [3–6]. Targeted drug delivery is divided into passive and active targeting [7], with active targeting having the ability to enhance the effect of passive targeting, making the nanoparticles more specific to the target and thus increasing the efficiency of delivery. However, both modes of delivery rely on systemic circulation and diffusion, during which the drug may degrade and be delivered extremely slowly, making it critical that the nanomachines remain under our control to perform their tasks. Reference [8,9] proposed a way of using relay nodes to release attractants to help clusters of nanomachines move quickly and directionally to a target area. Reference [10,11] proposed the use of a mobile molecular communication network of leaders and followers to achieve target detection, with the relay playing the role of a relay. Reference [12] proposed a single-hop relay directed communication model based on the convergence effect. In the presence of a relay, the nanomachine is able to reach the drug delivery area faster because it does not move blindly. However, if relay nodes are very far away from the straight line consisting of the start and destination, the drug-carrying nanomachine will have to turn around in the delivery process, which will result in drug degradation and inefficient transportation. Therefore, the location of the relay is very important; if the relay point is on or close to the straight line between the launch point and the target area, then the path is shorter ideally.

We propose a way to find the best relay node location, through which the nanomachines can reach the target area with a shorter path. The direction in which the relay nanomachine moves is controlled by two factors, the inertia of its own movement and the optimal point it reaches, and finally an optimal point is found, which is the optimal location of the relay nanomachine.

Section 2 describes the framework and system model, Sect. 3 describes the relay drug delivery mechanism, Sect. 4 analytically analyses the key parameters of finding the optimal location of the relay node, and Sect. 5 concludes the paper.

2 System Model

The application scenario is shown in Fig. 1 [13]. The approximate location of the tumor cell can be determined by medical imaging technology [14], then a big nanomachine carrying N small nanomachines is injected into the blood vessel wall near the tumor and is immobilized when the big nanomachine detects the highest concentration of microvesicles, which is the first step in the drug delivery process. At this point, the immobilized big nanomachine is equivalent to the "base" of the small nanomachine and the purpose of the framework is to deliver the drug from the base to the tumor cells. These N small nanomachines consist of M relay nanomachines and $N - M$ delivery nanomachines, where the relay

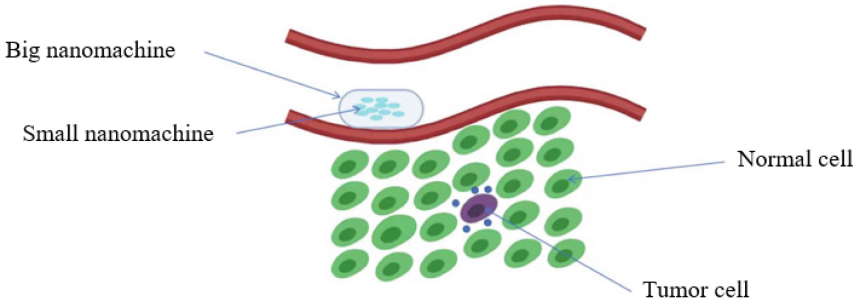

Fig. 1. Framework of the communication network

nanomachines do not carry the drug and will eventually become relay nodes between the base and the target, while the delivery nanomachines take on the task of delivering the destination. Unlike normal cells, cancer cells secrete more abnormal molecules, which would be a prerequisite for the nanomachine to detect the target.

In the second step, the big nanomachine is fixed to the vessel wall to become the base of the small nanomachine. First, M relay nanomachines will search for the optimal location of the relay node and fix it, and this process will iterate until m nodes have all fixed to form a path consisting of the base, the relay nodes and the destination, which will tend to be a straight line. The delivery nanomachines, carrying the drug, will then travel back and forth from the base to the destination via the relay nodes through the intercellular and extracellular fluid to deliver the drug [15,16]. Cancer cells can release abnormal molecules that distinguish them from normal cells, and the nanomachines will use these to target the cells.

The big nanomachines are injected directly into the vicinity of the diseased cells and move normally through the blood vessels without affecting other physiological phenomena; this paper focuses on how the relay nanomachines form the relay nodes in the second step.

3 Proposed Mechanism and Algorithm

As shown in Fig. 2, the aim of the nano-network is to form a path from the base to the destination through m relay nodes. The large circle on the left is the range of concentrations of repulsive molecules released by the big nanomachine, and the small circle on the right is the abnormal molecules released by tumor cells. The distribution of concentration of both molecules decreases from the center to the side of the circle. The two circles must have an intersection, which aims to ensure that the relay nanomachines don't get lost when finding the relay position. At the beginning, M relay nanomachines start to find the location of

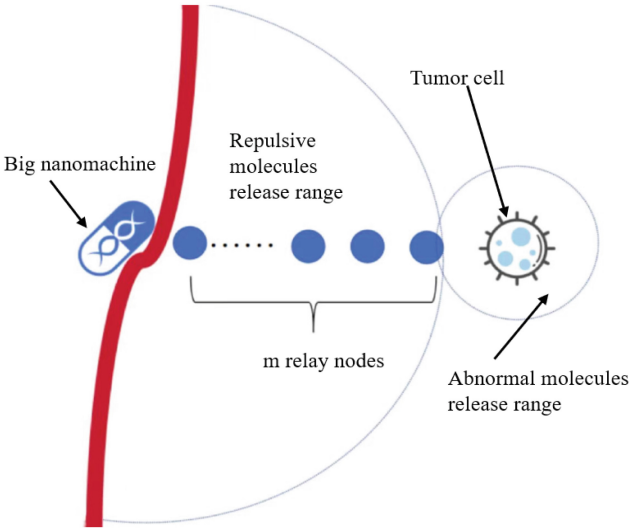

Fig. 2. Relay nodes in the line

the target from the base at that moment the big nanomachine starts releasing the repulsive molecule. In the presence of repellents, relay nanomachines will spread quickly. They have the memory function, they can remember the optimal location they have ever arrived at. The judgment of positional superiority or inferiority can be determined by the positional fitness Eq. (1). The distance of the relay nanomachine from the base or destination can be characterized by the magnitude of the concentration of the molecules it releases, with a higher concentration indicating a shorter distance. Thus, in the case where both types of molecules are detected, if the particle has a high fitness value, it means that the sum of the concentrations of the repulsive molecules ψ_r and the attractive molecules ψ_a is high, and therefore the sum of the distances to the target and the destination is the smallest and the nanomachine most likely to be on the straight line formed by them. The critivity of the position is determined by the fitness formula, and the process of finding the optimal position is the process of making the fitness value high, which is defined as follows.

$$y = \psi_r + \psi_a, \psi_r \neq 0, \psi_a \neq 0 \tag{1}$$

the latter qualification is meant to illustrate the notion that the nanomachine is adaptive only if both concentrations are detected at the same time, otherwise, it has no meaning. According to this positional fitness formula, the nanomachine can memorize and store the best position it has ever reached, and if a better y comes along, the nanomachine will clear its memory and remember this new y and its corresponding position. Their movement is controlled by two factors as shown in Fig. 3, one is the own mobile inertia v_{id} which includes the effects of attractants and repellents, and the other is the optimal position it has reached

$p^k_{d,pbest}$. Therefore, the velocity, actually the distance and direction in which the particle will move in the next iteration, i.e. a position vector in the $k+1$th iteration can be expressed as

$$v^{k+1}_{id} = \omega v^k_{id} + c_1 r_1 \left(p^k_{id,\text{pbest}} - x^k_{id}\right) \tag{2}$$

where c denotes the learning factor, the larger its value, the greater the influence of the corresponding component and r is a random number in the interval [0,1], adding randomness to the search. Similar to c, ω represents the degree of confidence in the direction of individual movement; the larger the value, the more inclined the particle is to continue at its previous speed and direction of movement.

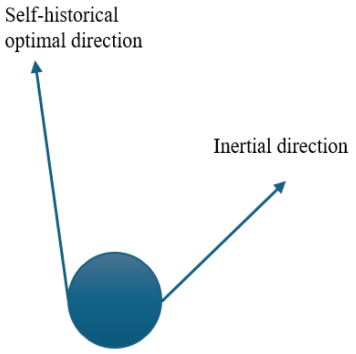

Fig. 3. Movement of the relay nanomachine

The position update formula is the current position plus the velocity of this step

$$x^{k+1}_{id} = x^k_{id} + v^{k+1}_{id} \tag{3}$$

where x^k_{id} and v^{k+1}_{id} represent the position vector of particle i in the dth dimension at the kth iteration and the velocity vector of particle i in the dth dimension at the $(k+1)$th iteration, respectively. Then a bottom threshold y' of fitness value is set for the M relay nanomachines. When the fitness value of the nanomachine is greater than this threshold it means that the closest location to the base-destination line is most likely to be in this neighborhood, namely the optimal region, otherwise, it means that this location is too poor to have sharing value. The first nanomachine to reach the threshold will fix and start to release the attractant A to attract other nanomachines to gather around it, which is called a leader nanomachine. Then an optimization problem to find the optimal position is

$$argmax\ y(position), \forall position \in \mathbb{P} \tag{4}$$

where $y(position)$ is the fitness value for certain positions and P is the space of all possible positions. The goal here is to find a point with maximum positional fitness, but since nanomachines only know their own positional fitness

value and not others', a threshold value $y*$ is required to be set, which will be larger than the previous threshold value. The first relay nanomachine to reach $y*$ will be fixed as the first relay node and release the attractant α. There will be another special case here, where the relay nanomachine is lucky enough to reach the best position, i.e. its corresponding positional fitness value y reaches $y*$, at which point it will directly immobilize and release the attractant α. The relay nanomachine will stop releasing attractant A and continue moving when it detects the attractant α. The attractant A will gradually degrade away and therefore will not affect the process of determining the second relay node $R2$.

The next step is to determine $R2$, which, unlike $R1$, is intended to be fixed between the base and $R1$, so that for the relay nanomachine the attractant α is greater than the abnormality signal released by the tumor cell. Therefore, when the relay nanomachine detects the attractant α, it will not be influenced by the abnormality of the tumor cell, and its process of finding the optimal position is the same as that of $R1$. Finally, $R2$ is fixed and begins to release the attractant β. This is iterated until m relay nodes are all fixed, and eventually a relatively straight path is formed.

Note that the attractants are divided into two categories: the first A is used to attract relay nanomachines to distribute them in a straight line, and the second is used to attract the delivery nanomachines during the process of carrying the drug. For the delivery nanomachine, as it travels from the base to the destination, the priority of the attractant is

$$\alpha > \beta > \gamma > ... \tag{5}$$

where there are m types of attractants to guarantee that delivery nanomachines pass through the relay nodes from the first to the last node and can complete the task by a shorter route. Once at the destination, they unload the drug and return to the base for the next round of drug delivery, in which process the priority of the attractant is reversed, which is defined as

$$\alpha < \beta < \gamma < ... \tag{6}$$

During the return process delivery nanomachines first pass through the mth relay node, and the movement path is opposite to the previous one, thus the priority of the attractants will also be opposite to ensure the return to the base.

It is assumed that the nanomachines move at the same speed and do not collide when they meet along the way.

4 Analytical Analysis and Discussion

Different parameter choices affect the speed of nanomachine convergence and the formation of final relay nodes. As the total number of relay nanomachines is also the number of candidates for the relay nodes, a larger value of M increases the number of fitness value scenarios, which allows the relay nanomachines to reach the threshold and $y*$ faster, thus increasing the efficiency of the search for the

optimal position, while too small a value of M indicates that a very small number of candidates are involved in the process of moving, which can make the search for the best position slow, thus affecting the system efficiency. The m as the number of relay nodes finally formed is also the number of attractants that the delivery nanomachine can detect, too large a number will slow down the process of determining the location of the relay node and complicate the mechanism for the delivery nanomachine because it needs to detect a corresponding number of attractants. In addition to this, too large a value will complicate the system and make it more difficult to implement, delivery nanomachines also can not recognize too many types of attractants with different priorities. While too small a number will tend to prevent the delivery nanomachine from detecting the attractants quickly and may not be able to achieve drug delivery along the shortest distances, relay nodes can not play the role.

The last is the setting of y' and $y*$, the former is to determine the optimal region and the latter is to determine the optimal location, thus $y*$ must be larger than y'. If y' is too large it takes too much time and resources for the relay nanomachines to reach the value, and if its value is too small it deviates too far from the optimal point and may even cause the leader nanomachine to attract the population to the region that deviates from the optimal point. If $y*$ is set too large then it is beyond the system level then it is meaningless and it makes little sense to spend too much time and resources reaching this value, if $y*$ is too small, the position of the relay node is similar to the leader nanomachine then the process of finding the optimal value is meaningless and the position will be not ideal. $y*$ should be in a relatively high range.

5 Conclusion

In the targeted drug delivery scenario, since the drug-carrying nanomachines have to travel back and forth many times, the formation of shorter paths from the base, relay nodes and the destination is of great importance for reducing drug loss and improving delivery efficiency. The principle of the method and the realization process are described in detail.

The selection of parameters is discussed, and future work will focus on using it for practical experiments and analyzing the corresponding convergence performance.

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