Modeling Nanonetworks Connectivity in the Blood Flow

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ABSTRACT

This work addresses a study of the connectivity of a cohort of nanorobots in the circulatory system (blood) which is modeled as a cylinder. The trajectories of the nanorobots are computed according their velocity, type of flow (laminar vs turbulent varying the diameter and length. THz omnidirectional and optical directional communications are considered where ranges are around 10 mm. Connectivity results show a strong dependency of the diameter of the vessel, the larger the better. Moreover, capillary vessels are not considered as nanorobots are very sparse requiring a huge number for useful utilization.

CCS CONCEPTS

• **Networks → Network reliability**.

KEYWORDS

Nanonetworks, biomedical applications

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1 INTRODUCTION

This work addresses the connectivity of a cohort cooperative of nanorobots in the circulatory system. This allows cooperative actions such as targeted drugs delivery and sensing (temperature, PH, disease indicators, etc.) that could help to detect malfunctions in the organism at an early stage. Interconnecting nanomachines in a nanonetwork overcomes the limitations of individual nanodevices expanding their capabilities in terms of both complexity and range of operation, by allowing them to coordinate and share information.

1.1 Circulatory system

Approximately 84% of the body's total blood volume is in the circulatory system, 64% in the veins, 13% in the arteries and 7% in the systemic arterioles and capillaries [3]. The speed is on average 33 cm/s in the aorta meanwhile the speed in capillaries is only 1/1, 000 of that, i.e., approximately 0.3 mm/s. However, because the capillaries are only 0.3 mm long, the blood only stays there for 1-3 seconds [3]. Most capillaries are only about 8 to 10 μm in diameter [7]. The physiologic blood flow in vascular hemodynamics is mainly assumed to be laminar. Laminar flows presents parabolic distribution of velocities $v(\rho)$ (see figure 1). However, close to the heart where the velocity is high with important bifurcations, blood flow can be turbulent our model considers the addition to laminar flow of a random direction $+v_{turb}$ varying from 0 to $v(r)$.

The diameter of the circulatory system vessels limits the size of nanorobots, they have to be small enough to pass through capillaries, i.e., smaller than, approximately, 5μm and larger than 6 nm not to be cleared from the body through the renal route [4].

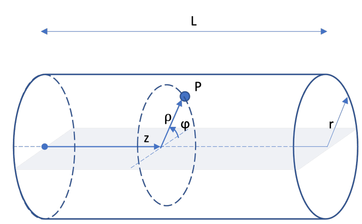

Figure 1: Cylindrical coordinates

1.2 Nanoscale Communications

In this paper, electromagnetic communications (terahertz and optical) are selected where the very small size of nanoantennas imposes the use of very high frequencies for electromagnetic wireless communication between the nanomachines. This ranges from the terahertz band (0.1-10 THz) to the infrared and visible optical frequency bands (200-600 THz) and presents many challenges as well as new opportunities for electromagnetic nanonetworks [1] and [5]. Indeed, as in other wireless networks, the communication between two nodes can be realized through relaying data to other nodes. For efficient constrains, all nodes do not relay data, it is a multi-hop decision algorithm managing which nodes are entitled to do so. In [6], these aspects are addressed on the case of sensor networks.

1.3 Simulation Model

A set of experiments are performed to compute the connectivity of a set of nanorobots in a segment (a cylinder with length L and radious r) of the circulatory system. The position of a nanorobot P is represented in cylindrical coordinates $\{\rho, \varphi, z\}$, where ρ is the radial distance, φ is the angle coordinate and z is height (the distance to the origin of the cylinder) as shown in Figure 1.

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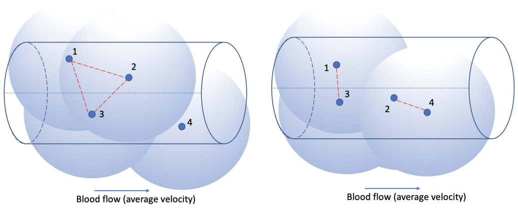

Figure 2: Omnidirectional links (left t_i, right t_{i+1})

1.4 Connectivity Computation

For THz electromagnetic communications, directional links are not considered. However, for optical communications, directional links are considered as a suitable option due to the intrinsically short range for omnidirectional links. Therefore, the connectivity depends on the distance between nodes (as for omni directional links) and on the angle relative to the direct line of sigh [2].

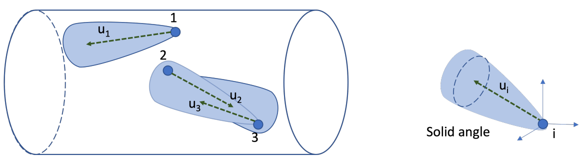

Figure 3: Directional links

The radiation pattern follows a 3D lobe shape. Figure (3) shows the main lobes of nanorobots 1, 2 and 3. The solid angle Ω represents the fraction of the covered surface of an sphere. In the example of Figure 3 (left), nodes 2 and 3 can exchange information, however, nodes 1 and 2 cannot although they are actually in range due to the miss-alignment of their lobes.

2 SIMULATION RESULTS

2.1 THz communication (omnidirectional)

The Average Two Terminal Reliability (ATTR) is the selected connectivity metric for the defined scenarios varying the range (0.004 to 0.012) and the density of nanorobots (1 to 10 nanorobots per cm^3). Y-axis corresponds to the connectivity metric ATTR.

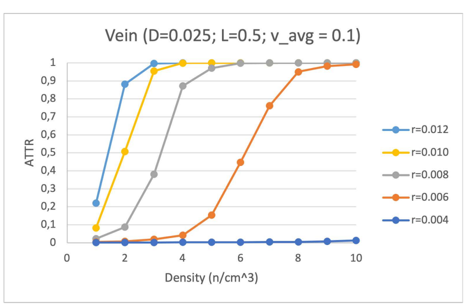

Figure 4: Vein ATTR THz Omnidirectional

As expected in all scenarios the connectivity increases with larger range and density. When comparing different diameters, large veins (Fig 4) vs medium veins (Fig 5), the diameter of the vessel, is crucial. As the diameter decreases, the nanorobots communications become more difficult. No significant differences are observed between arteries and veins on top of their diameters.

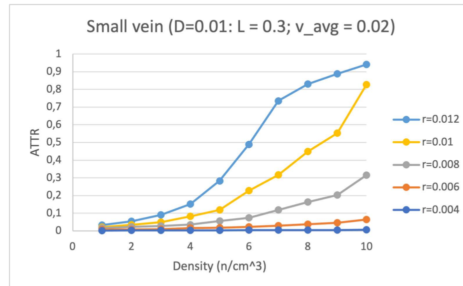

Figure 5: Small vein ATTR THz Omnidirectional

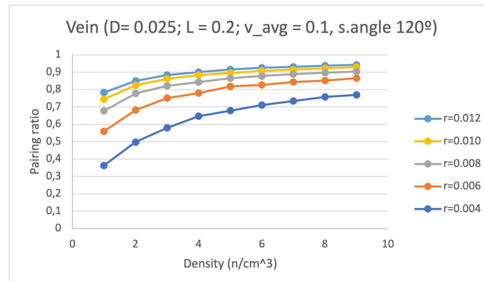

Figure 6: Vein. Pairs ratio Optical Directional

2.2 Optical communication (directional)

For the optical communications, the only considered networks are formed by pairs, i.e., once two nanorobots are in range and well oriented. This set of results shown again a major impact of the diameter of the vessel and the density of nodes see figure 6. The selected solid angle is 120 degrees. When reducing the diameter for small veins the pairing ratio is slightly smaller, this is a different trend compared to THz communications.

3 CONCLUSIONS

Range and density are the most relevant parameters. When the diameter of the vessel decreases the topology of the network is modified making more difficult the connectivity. Small vessels (including capillarity) present very small volume (of blood) hence connectivity is almost impossible.

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