BVS-Net: A Networking Tool for Studying THz-based Intra-body Communication Links

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ABSTRACT

Developing simulation tools for the internet of bio-nano-things (IoBNT) aims to support future medical applications in future healthcare technologies. In this paper, we focus on the communication of in-body nanobots with an out-of-body gateway to evaluate data transmission efficiency, identify potential obstacles, and optimize their design for practical applications. In particular, we introduce BVS-Net, an ns-3 module that models the terahertz communication channel between nanobots flowing with the bloodstream and an external gateway attached to the skin surface. We provide open access to the BVS-Net code to support further developments within the research community.

CCS CONCEPTS

• **Networks** → **Network protocol design**; • **Applied computing** → **Life and medical sciences**.

KEYWORDS

Internet of Bio-Nano-Things, Blood System, Network Simulation

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1 INTRODUCTION

BloodVoyagerS (BVS) allows simulating the movement of nanobots within the human circulatory system; see [1]. The framework simulates the mobility of nanobots within all the major blood vessels and was later enhanced for supporting communication between nanobots as described in [3]. However, a module simulating an intra-body communication link between nanobots and a terahertz band gateway is still missing. Overcoming this limitation, this paper introduces BVS-Net, a flexible ns-3 component following our previous theoretical work in [5], which follows the schematic shown in Fig. 1. Leveraging on the popular development of ns-3 components for wireless links [2], our module provides an interface for intra-body links in the terahertz band between nanobots flowing within the bloodstream and the on-body gateway device.

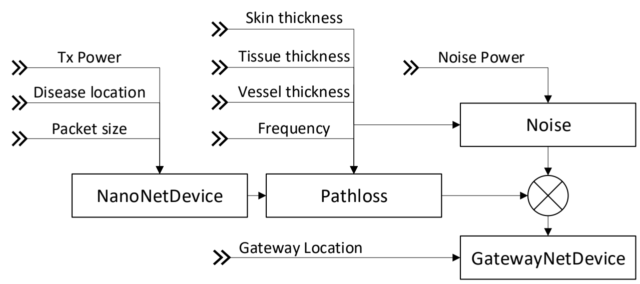

Figure 1: Block diagram of intra-body link.

The proposed interface models a networking device in each nanobot in the blood vessel and simulates the transmission of binary data and their propagation through the human tissue. We model the communication channel between nanobots and the gateway using necessary physical propagation properties of the blood vessel [5]. On the receiver side, we designed a networking device at the skin level that simulates data reception and cache.

Our main contributions can be summarized as follows:

- We developed a simulation tool supporting terahertz communication from in-body nanobots to an external gateway[1].
- We validated the module by simulating the path loss, noise, and their impact on packet error rate during data transmission through human tissue.

2 IMPLEMENTING INTRA-BODY LINKS

We implement a communication module extending BVS that supports terahertz communication. Nanobots start the transmission at a predefined gateway location. The data delivery accounts for the packet emission using on-off keying (OOK) modulation. The waveform propagation using the corresponding channel model was implemented as given in [5, Eq. (2)]. The constellation points are rendered at the receiver to estimate the bit error rate. A schematic representation is shown in Fig. 1. The module considers different physical properties of intra-body communication links such as the thickness of the tissue. Other parameters, like the blood speed and vessel lengths, are provided by BVS. For the data generation, the module allows the specification of the transmit and noise power

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[1]Our code is available as open source https://github.com/tkn-tub/BVS_Net

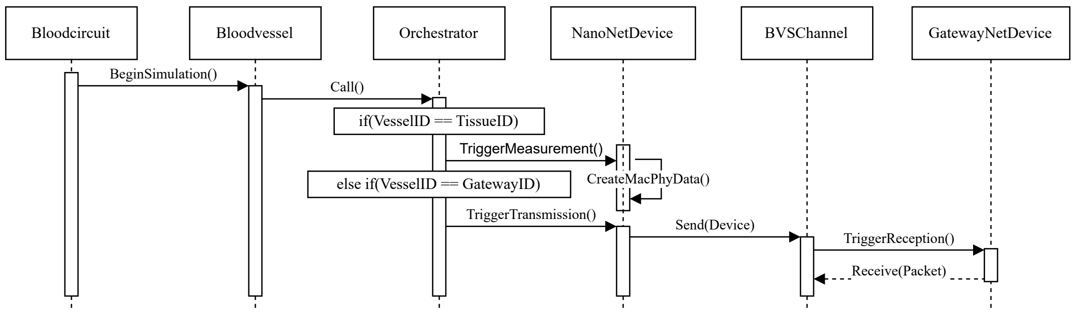

Figure 2: Sequence diagram for a simulation step in BVS-Net.

and the size of a transmission data packet. It then generates a random sequence of bits whenever a nanobot passes through a given disease location. We also include disease and gateway locations with the vessel coordinates as input parameters.

The processing of the message and the involved modules are depicted in the sequence diagram in Fig. 2. At each simulation step (configured as 1 s), vessel objects move the nanobots and query in the `Orchestrator` class, whether their current position is close to the gateway device or within the disease location in the human body. `Orchestrator` is a helper class, i.e., not a part of the system model, only to trigger communication between nanobots and gateways and can be extended to orchestrate this process with additional features. The nanobot generates a random sequence of bits for the data packet (`createMacPhyData()`) when reaching out to a given disease location and initiates the transmission of data (`Send()` and `Receive()`) after reaching out to the gateway. These two functions for sending and receiving using the ns-3 architecture, which not only allows swift integration of the model but also offers flexibility for further extensions.

3 PERFORMANCE EVALUATION

We performed simulations using our BVS-Net module using the parameters listed in Table 1 for validation. Skin thickness has been taken from [4]. Vessel thicknesses vary greatly depending on the location in the vascular system. For this initial experiment, we iterated over a varying vessel thickness. This simulates the nanobot position within the vessel when traveling along various blood vessels. The packet error rate (PER) is evaluated with the Monte Carlo simulations comparing the emission of 1500 packets with the received packets per vessel thickness value as illustrated in Fig. 3. We observe that the communication link is error-free when the nanosensor travels at a depth less than 200 µm in the blood vessel. We also plot the received OOK constellation points at the receiver in Fig. 3 for a vessel thickness of 160 µm. We observe that the impact of noise in the communication link produces a dispersion of the constellation point in the in-phase axis.

Table 1: Simulation parameters

Packet size	200 bits	Rx-Tx distance	500 µm
Transmit power	1 mW	Vessel thickness	160 µm
Frequency	0.5 THz	Epidermis thickness	76 µm
Modulation	OOK	Dermis thickness	1 mm
Noise Power	4.3×10^{-21} W	SNR	1.5 dB

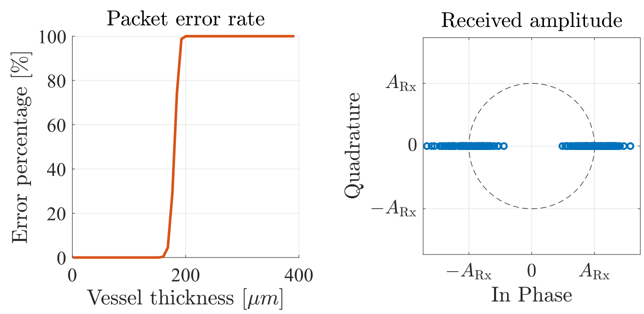

Figure 3: Packet error rate and received constellation (OOK), where $A_{\text{Rx}} = 1.1 \times 10^{-10}$ V is the amplitude.

4 CONCLUSION

We introduced an open-source simulation tool, BVS-Net, for terahertz intra-body communication links. It accounts for wireless data transmission between nanobots and a skin-level gateway in the terahertz band. We integrated our module with BVS using the ns-3 architecture. We foresee BVS-Net as a tool for further studies and performance evaluation in nano communication applications.

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