A Simulation Framework for Connecting In-Body Nano Communication with Out-of-Body Devices

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ABSTRACT

We present a novel simulation framework bridging the gap between in-body nano communication and out-of-body body area network (BAN). We assume nanobots freely flowing within the blood system. Their mobility can be modeled using the BloodVoyagerS module. The communication channels are modeled using proximity (nanobot to nanobot), proximity and ultrasonic communication (nanobot to a gateway), and standard IEEE 802.15.4 for BAN communication. In our simulation framework, we rely on ns-3 to model all the three independent communication channels to, for the first time, study the end-to-end communication performance from nanobots to a connected host system. We consider the system a fundamental basis for more advanced studies of such integrated and very heterogeneous communication systems.

CCS CONCEPTS

• **Networks** → **Network simulations**; • **Computing methodologies** → *Model development and analysis.*

KEYWORDS

Simulation tools, nano networks, body area networks

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1 INTRODUCTION

In the context of improvements in medical treatments, computer science has gained significantly in importance over the last years. The increasing interest is reflected in research topics such as developing body area network (BAN)-based sensor systems [2] to continuously monitor patients, or new technologies to build devices at nanoscale [1] that will be able to freely move within the body. Since all of these research topics are working with, on, or in a human body, it is important to provide detailed simulations not only of the new technologies but also of the physical environment in which these technologies should be deployed. This connection between in-body nano communication and out-of-body BANs is still not sufficiently explored [3]. Particularly the interconnection between the different components is of interest, as this is not covered by existing simulation frameworks.

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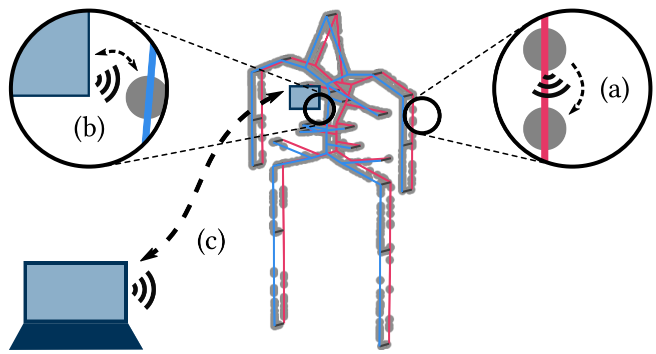

Figure 1: Communication paths between: (a) different nanobots; (b) nanobots and gateway, e.g., via ultrasonic communication; and (c) gateway and smart device via an IEEE 802.15.4 network.

Figure 1 outlines the involved components and the communication links. At the core, the blood system is depicted, which allows nanobots to travel within the human body. Related mobility aspects can be modeled using BloodVoyagerS [4], which simulates the circulatory system of a human body and nanobots moving around in the blood vessels. The nanobots are moving with a constant velocity through the body like a regular blood component, depending on the vessel they are currently in. BloodVoyagerS, which is implemented as a freely accessible ns-3 module, provides coordinates that reflect their positions in the human body.

Our novel simulation framework makes use of these nanobot positions to simulate the communication using, in a first step, proximity-based approaches. For communication from nanobots to the outside an ultrasonic link is assumed. This is in line with recent findings on suitable communication paths through larger-scale tissues [5]. Finally, the link from this gateway to a host system is provided by standard IEEE 802.15.4 links.

The goal of our framework is to assess the performance of the system as a whole, allowing to study end-to-end communication protocols. Since it closes the gap between in-body and BAN communication technologies, the framework presents a powerful tool for studying the aforementioned technologies for the detection and treatment of illnesses.

2 SIMULATION FRAMEWORK

Like BloodVoyagerS, our framework is implemented as a set of modules within the ns-3 network simulator. The first part of the architecture is the outer-body part, which describes the end-to-end connection between a host system (e.g., laptop) and a gateway via an IEEE 802.15.4 link. Nanobots also have to be able to communicate with each other to share information received through the gateway or which they themselves gathered to forward it towards the gateway. Thus, the second and third part deal with the communication between nanobots and a gateway, and the communication among the nanobots, respectively. Both of these links are abstracted using a proximity approach without any processing delay at nanobots.

The link between laptop and gateway (link (c) in Figure 1) is based on the ns-3 implementation of the IEEE 802.15.4 standard. Both systems are modeled as ns-3 nodes with an additional IEEE 802.15.4 netdevice, using the PHY and MAC layer implementation of the protocol. Furthermore, the simulation framework includes an application layer at the laptop, providing an interface for users to give input to address nanobots. The application layer is implemented as an ns-3 header for data packets. The ns-3 header is a simple way to add data to packets and to read data from a packet received at a destination node.

The gateway located on the body can use a proximity-based channel to exchange packets with nanobots. We made the assumption that the gateway is positioned on the chest above the left heart chamber. Consequently, every nanobot which is in the left heart chamber and therefore nearby is able to copy a message from or to the gateway. The gateway adds a sequence number to every packet received by the laptop so nanobots are able to remember if they saw this packet before. A tag is set if a packet is addressed to nanobots. By reading this tag, nanobots can decide whether they have to disassemble the packet or just forward it. The gateway can forward packets received by nanobots to the laptop after removing the sequence number and the tag.

For the nanobot to nanobot connection, another proximity approach is used. Here we assumed that nanobots can exchange packets if they are close enough to each other. For a proof-of-concept, we set this communication range to 1 cm. The current configuration foresees that a nanobot which has already received a message will try once every second to copy its message to all other bots in its vicinity. A nanobot can disassemble packets and check if the packet is addressed to itself by checking the ID range, functionality, and body area provided in the packet. A nanobot accomplishes a task when receiving the packet.

3 EVALUATION

Figure 2 shows the latency of delivering a packet from laptop to every nanobot within the body if 1000 or 6500 nanobots are present in the body. The results are obtained in a system in equilibrium [4].

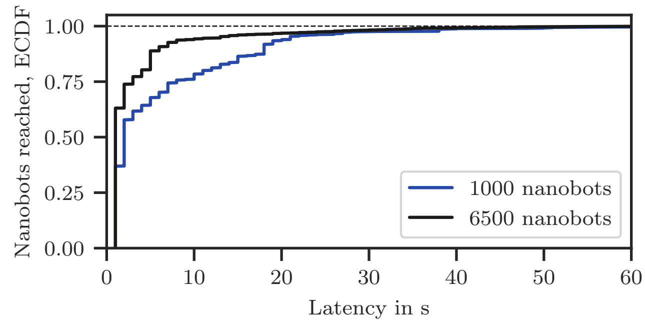

Figure 2: Fraction of nanobots as a function of latency.

In both cases, the first nanobots receive the packet by the time 1 s has passed. As there is no transmission or processing delay simulated for the packet exchange, at least half of all nanobots receive the message by 2 s in the 1000-nanobots case or already by 1 s in the 6500-nanobots case. It can be seen that even though nanobots are distributed over the whole system, it takes 145 s for the packet to reach all 1000 bots and 63 s to reach all 6500 bots. This can be attributed to the fact that the distribution of nanobots is not perfectly uniform [4] and to the limited communication range.

4 CONCLUSION

We presented an overview on a newly developed simulation framework for connecting in-body and out-of-body communication as an ns-3 module. A first evaluation of the simulation framework emphasizes the impact of the distribution of nanobots on minimizing packet delay. Since many abstractions were assumed for this paper, there is potential to make this framework more realistic by using, for example, an ultrasound communication link [5] for the packet exchange between gateway and nanobots, or molecular communication among nanobots. In future work, we will integrate part of the required models and also plan for larger scale simulations.

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