Age of Information in In-Body Nano Communication Networks

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ABSTRACT

The use of nanobots and in-body nano communication techniques offer manifold options for next generation health care and precision medicine. Scientific progress allows to place nanobots in the human circulatory system and enabled them to exchange data and information among each other as well as to external gateway systems. One of the frequently asked questions is how to identify the optimal number of bots for a task, monitoring frequencies, and communication technologies. In this paper, we introduce and study the age of information (AoI) as a comprehensive metric for describing the performance of in-body nano communication networks. We use the AoI concept in an in-body measurement scenario. Our results clearly demonstrate that AoI is a very helpful tool to study the performance of in-body nano communication networks.

CCS CONCEPTS

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

KEYWORDS

Age of Information, Nano Networks, In-Body Networks

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1 INTRODUCTION

Recent advances in nano communications and the integration of in-body with body area networks act as key enablers for next generation medical devices [1, 2]. In our application scenario, smart devices patrolling the human body, such as nano robots, are simulated to account for their connection to each other but also to a gateway that is able to communicate to a smart device located outside the human body [5]. It is possible to control the nano-devices to execute tasks in the body or evaluate data that can be collected in a minimally invasive and precise way. Reliability and real-time data delivery are some of the most important requirements of such frameworks. The age of information (AoI) [4] can serve as a metric for calibrating these factors of the simulation tools, developed for such crucial domains, as it provides an estimate of the *freshness of the information* generated by the source.

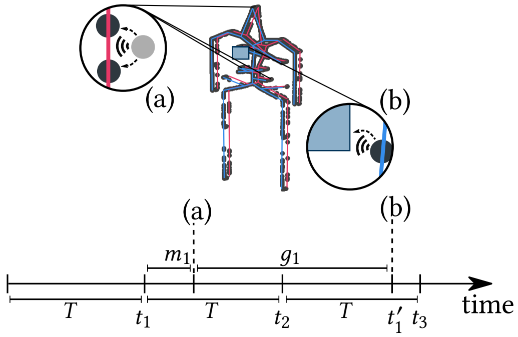

Figure 1: System model showing nanobots traveling through the cardiovascular system. The time sequence indicates the actions from message generation to delivery to a gateway. t_1, t_2, t_3, etc. indicate the time a status update is generated. This update is handed to a moving nanobot (a) after some delay m_1 and delivered to the gateway (b) after some additional traveling time g_1. T indicates the message generation interval.

AoI takes into account not only the propagation delay but also the packet generation time at the source. It is an end-to-end metric that characterizes the freshness concerning a status updating system [6]. To that end, it defines the age of a generated packet as a linear function of time. From the receivers perspective, the age will be updated with every received message. This results into the so-called peak age of information (PAoI).

Nanobots have been proposed to cooperatively support medical applications such as monitoring or drug delivery [2]. In this paper, we introduce a framework to study the AoI for a nanobot-based application. We follow the system model in [5], which makes use of nano communication between the nanobots and ultrasonic communication to a gateway carried by the person. Our findings show that AoI is a very suitable metric, which can eventually be used for comparing different communication techniques, to find sweet spots

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in the number of nanobots and their movement, and to find best configurations of sensor located at relevant positions in the body.

Our major contributions can be summarized as follows:

- We introduce the application of the age of information in nano communication networks;
- we implement the AoI metric in an in-body measurement scenario, which relies on periodic sensor measurements and the transport via nanobots to a gateway; and discuss first simulation results.

2 USING AOI TO CHARACTERIZE NANO COMMUNICATION NETWORKS

For calculating the average PAoI of the system, we need to calculate the time when the first instance of a particular status update packet is received at the gateway [6]. Figure 1 shows the system model as well as a time line of selected events. Obviously, the location of source and destination play a vital role in the calculation of the PAoI. In our framework, we have to calculate the PAoI at the gateway regarding a given body region. It may happen that multiple nanobots collect the same status update packet from the stationary nanodevice and deliver it to the gateway, however, this is not improving the freshness of information at the gateway. These packets will be discarded when received.

Each packet, after generated, will be delayed because of the time elapsed since the generation of the status update packet until it is copied by a moving nanobot, denoted as m_i; and the time required by the moving nanobot to reach the gateway, denoted as g_i. Thus, the perceived PAoI in the gateway is given as:

$$\begin{aligned} A_i &= T + (n_i T) + D_i \tag{1} \\ D_i &= m_i + g_i, \tag{2} \end{aligned}$$

with i being the i-th message received at the gateway and n_i the number of messages generated but not delivered since the last successful delivery of a control message, i.e., $n_i = 0$ when previous and current generated messages are successfully delivered. Please note that we assume a constant update interval, thus, T is not dependent on the message counter.

Our simulation framework Communication-BloodVoyagerS (C-BVS), implemented as an extension of BloodVoyagerS [3], is modelling nanobots that are moving in the human circulatory system. It mainly consists of four parts, the physical environment, the nanobots moving within it, a gateway located on the body and a laptop for controlling the nanobots from outside the body [5].

3 EVALUATION

We particularly looked at the time average PAoI as experienced in our system. To see the impact of the system parameters, we explore the PAoI for three different locations of monitoring bots in the circulatory system (brain, liver, kidney) as well as for five different nanobot quantities and three different monitoring intervals. Figure 2 shows selected results for the kidney location. We can observe the following interesting artifacts from our results: First, PAoI increases as the monitoring interval T increases. This is to be expected as PAoI is directly proportional to T. Secondly, the number of nanobots deployed in the circulatory system plays a very important role. For small number of nanobots, status update packets may not be picked up before getting refreshed after T. Third, the location of the monitoring bot in the body matters. This influences the average traveling time g toward the gateway.

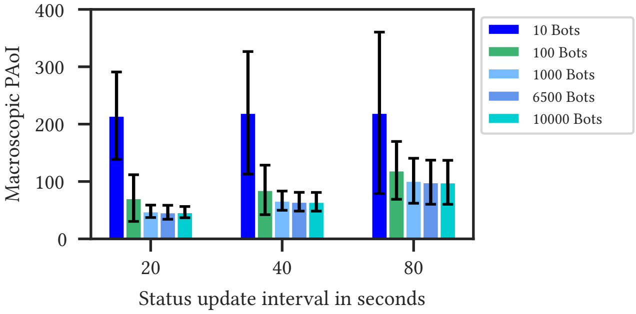

Figure 2: Macroscopic PAoI (in seconds) for the kidney region for varying status update intervals and numbers of nanobots injected into the circulatory system. The error bars indicate the standard deviation.

4 CONCLUSION

We have introduced and studied the AoI as a comprehensive metric for describing the performance of in-body nano communication networks. In particular, we integrated the PAoI concept in an in-body measurement scenario to perform a first study on the impact of selected design decisions. Building upon our previous work on the C-BVS simulation framework, we calculated the freshness of the status update packets generated by stationary nanobots at different locations in the human body from the receiving gateway's perspective. We have found that, for our system, the number of nanobots injected, the status update interval, and the visiting probability affect the freshness of information. In general, it holds that increasing numbers of nanobots as well as reduced status update intervals help reducing the PAoI.

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