Jamming to Support Privacy-preserving Continuous Tumour Relapse Monitoring Using In-body Radio Signals

Thiemo Voigt, Wenqing Yan, Laya Joseph, Sam Hylamia[*]
Uppsala University, Sweden
firstname.lastname@it.uu.se

Noor Badariah Asan
CeTRI, FKEKK
Universiti Teknikal Malaysia Melaka, Malaysa
noorbadariah@utem.edu.my

Maria Mani
Department of Surgical Sciences,
Uppsala University, Sweden
maria.mani@surgsci.uu.se

Bappaditya Mandal, Mauricio Perez, Robin Augustine
Uppsala University, Sweden
firstname.lastname@angstrom.uu.se

ABSTRACT

Early detection of cancer can significantly improve the quality of life for cancer patients, as well as increase their chances of surviving and reduce treatment costs. We have earlier shown that human adipose (fat) tissue can be used as a propagation channel for radio frequency communication within the human body. A potential application of this technology is the continuous monitoring of the growth of perturbants, such as tumours, in the channel. We have earlier addressed the privacy issues associated with the deployment of this monitoring technology caused by the information leakage. We have proposed a set of privacy-enhancing techniques that together reduce this information leakage and hence protect the patients' privacy. In this work we propose to augment this scheme by having the aggregator, the gateway between an intra-body sensor network and the outside world, jam during measurements to further enhance the privacy protection of our scheme.

1 INTRODUCTION

While cancer annually causes the death of millions of people [7], early detection and consequent treatment can improve the quality of life for cancer patients, increase their chances of surviving and reduce the treatment costs [7]. Recurrence of a cancer may occur if some of the original cancer cells survive the initial treatment [1].

In this context in-body sensor networks may play an important role in detecting cancer recurrence. We have shown that the human fat tissue can serve as a propagation channel for microwave radio communication, for example, using RF in the 2.4 GHz band [2]. An in-body communication channel is useful since, as life-expectancy increases, more patients have multiple implants. These implants collect vital information about patients' health status, perform targeted drug delivery (possibly by distributed control loops of sensing and delivery devices) and replace non-functioning organs with artificial ones. Further, transmitting data out of deeply implanted devices is difficult; on the other hand, an in-body communication channel makes it possible to transfer data to devices located in parts of the body where it is easier to couple out the signals.

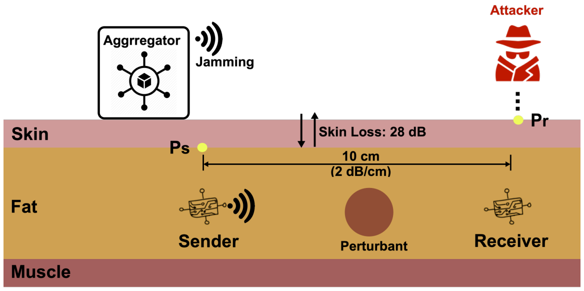

Figure 1: Scenario: A perturbant (tumour) growing in adipose tissue between skin and muscle.

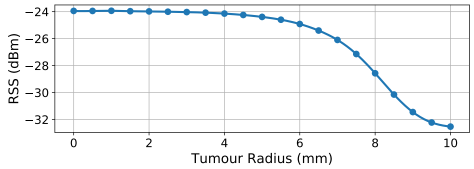

Figure 2: As the tumour is growing, the RSS decreases.

This technique may also be used to monitor tumour recurrence by observing changes in received signal strength (RSS) over a long period. Figure 1 shows the setup and Figure 2 the result of a simulation demonstrating the effect of a growing tumour on the RSS. The figure shows that as the tumour grows in size, the RSS decreases. Monitoring this change over time can reveal the presence of a perturbant in the channel enabling early medical examination and initiation of appropriate treatment.

From a privacy perspective, this is a challenging scenario since radio transmissions, like those in Figure 1, radiate outside the body as skin does not absorb or reflect the signals completely [3]. Hence, there is a risk that an eavesdropper could infer the growth of a perturbant in the channel by exploiting such signal leakage and, thereby, violate patient privacy and reveal information about patients' health status. Parties interested in such private data include insurance companies and potential employers.

In earlier work [5], we have proposed a set of privacy-enhancing techniques that together are able to reduce this information leakage: Random and adaptive variation of output power, channel hopping, as well as sender anonymity. In this work, we demonstrate that the aggregator can assist the implanted devices by transmitting jamming signals while the implants perform their measurements. Such friendly jamming has been employed by others as well [4, 6]. We expect that this jamming will impact off-body attackers much more than the implanted devices due to the signal loss offered by human skin. We device novel measurements to quantify the latter.

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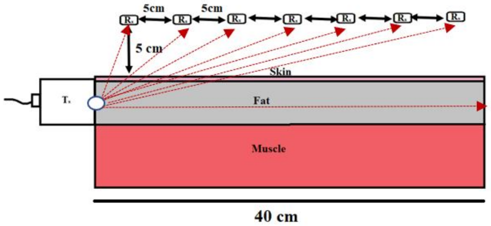

Figure 3: Setup to measure the loss offered by human skin.

2 SYSTEM MODEL AND ADVERSARY MODEL

As in our previous work [5] we consider scenarios, such as the one in Figure 1, where two devices are implanted on opposite sides of a high probability tumour relapse area. The devices send and receive messages through the fat layer that connects them and can coordinate their actions. The periodically exchanged messages are encrypted and tamper-proofed.

We consider a passive eavesdropper able to pick up transmissions originating from our monitoring system. It can measure the RSS of the messages it detects, but it cannot decrypt these messages, tamper with their content nor inject additional messages. The eavesdropper is off-body but can be close to the surface of the skin above the monitoring area for as long as the monitoring system is operational. Additionally, we assume that the eavesdropper knows where the monitoring devices are implanted and the role of each device. We choose this powerful adversary to model a worst-case scenario.

3 SIGNAL LOSS WHEN PENETRATING SKIN

In order to estimate the signal loss when penetrating the skin, we develop a phantom, i.e., an artifact that mimics the properties of human tissue. We use an oil-surfactant based phantom. Unlike water-based phantoms, the dielectric properties of such phantoms are not affected by moisture loss. As shown in Figure 3, we place a free space optimized receiver RX antenna vertically above the three-layer phantom with 5 cm spacing. A fat-matched transmitter TX antenna is placed at the edge of the 3-layered fat channel. We take measurements 5 cm apart from each other at seven different positions. The total path loss at each position is calculated at each measurement point. The loss in the fat layer (2dB/cm) is known [2] and since free space loss is substantially lower than in-body loss we have not considered it in our approximation. The skin loss is then attributed as the difference between the total received signal and the losses within the fat layer. In our measurements, the skin loss value is consistent across all seven points and our empirical results show that the loss offered by a 2 mm thick skin layer is approximately 28 dB.

4 EFFECTIVENESS OF JAMMING

In order for the jamming to be effective, the following conditions must hold. C 1: At the attacker, the strength of the signal from the jamming aggregator must be stronger than the one from the in-fat sender. C 2: at the in-body receiver, the strength of the signal from the sender must be stronger than that of the jamming aggregator.

We compute the path loss between the sender (sender or aggregator) to the attacker or receiver using the following models: a) for communication in air, we use the free space path loss model (FSPL) for 2.4 GHz b) for communication within the fat channel, we assume a path loss of 2 dB/cm [2] and c) for signals travelling through the skin, we assume a path loss of 28 dB (see previous section). The loss in the fat channel is constant (in dB per cm) since the skin and muscle around the fat act as a waveguide.

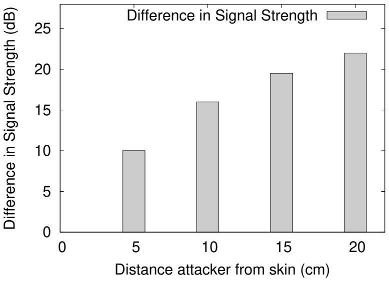

Figure 4: Difference in Strength of Signal from Aggregator and Sender at the Attacker

So, for example, for C 1 to hold, assuming sender and aggregator transmit with the same output power, the path loss between sending entity and attacker must obey the following condition:

$$FSPL(aggregator, attacker) < PL(sender, P_s) + PL(skin) + FSPL(skin, attacker) \quad (1)$$

Assume a sender and receiver implanted in a breast with a distance of 10cm from each other and an aggregator placed 50cm from the breast on the thigh (since it is easy to couple out signals there). Also the attacker has a distance of 50cm from the sender. We vary the distance of the attacker from the skin and compute the difference in signal strength of the two signals at the receiver. In all cases, the signal from the aggregator is stronger. The results in Figure 4 show that the difference in signal strength is up to 24 dB (ca. 250 times stronger) when the attacker is 20cm from the skin. Computing C 2 in the same manner also shows that at the receiver, the signal from the sender is much stronger than that of the aggregator since the latter signal must travel through skin which alone causes a loss of 28 dB while 10cm in fat only causes a signal loss of 20 dB. **Conclusions.** These initial results suggest that it is possible to use jamming signals from the aggregator to support privacy-preserving tumour relapse monitoring in the fat channel.

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