

BER Performance Analysis of Implantable Antennas in a Dynamic WBAN Channel

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Abstract— Subcutaneous implantable devices have significant potential applications in Wireless Body Area Network (WBAN) systems. However, achieving a reliable wireless link between in-body devices and external terminals (e.g., Wi-Fi) is challenging due to the reduced radiation efficiency caused by the electromagnetic (EM) effects of human inner tissue. Current systems, such as capsule endoscopy, often rely on repeaters attached to the human body to establish this link. In this study, we investigated the communication performance of implantable antennas in realistic human dynamic channels using an arm-swinging human phantom, while considering multipath propagation effects through Monte Carlo simulations. The antennas were implanted at a depth of 5 mm below the body surface at two different locations: the waist and the wrist. The goal was to evaluate the primary factors affecting implanted antenna performance, such as electromagnetic (EM) effects of human tissue, dynamic shadowing, and polarization mismatch in typical WBAN scenarios. The results reveal that when a single dipole antenna is implanted under the skin at the waist, the shadowing effects caused by arm-swinging can be mitigated by relocating the antenna from the waist to the abdomen. Additionally, for a dipole implanted under the wrist skin, although polarization mismatches with the radio-wave propagation environment occur, the bit error rate (BER) degradation of QPSK signals is less severe compared to waist implantation. Furthermore, when using a two-element dipole array, the maximum ratio combination (MRC) method provided a slight improvement in BER performance compared to selection diversity for both waist and wrist implantation scenarios.

I. INTRODUCTION

Smart healthcare systems have evolved tremendously over the last decade, enabling seamless monitoring of diverse physiological information within the human body in real-time scenarios. Significant progress has been made in the development of smart biomedical systems, including artificial retinal prostheses, endoscopic capsules, and brain-machine interfaces [1]–[3]. To meet these growing demands, in-body wireless communication systems utilizing ISM (Industrial, Scientific, and Medical) frequency bands are gaining significant attention [4]–[6]. In traditional in-body communication systems, such as capsule endoscopy, patients are required to swallow the capsule and attach a data recorder, comprising a receiving sensor array antenna attached to their body [7]. This is primarily due to the low transmission efficiency of implantable or in-body devices, which results from the reduced antenna radiation efficiency caused by the electromagnetic effects of human tissue. Additionally, the

performance of body-worn recorders is often impacted by dynamic shadowing effects caused by human movement, further complicating the ability to maintain a reliable wireless link with external terminals [X]–[X]. Therefore, although extremely challenging, the ultimate goal of implantable device technology is to enable direct communication between these devices and external terminals without the need for body-worn repeaters.

In this study, we analyzed the communication quality of a typical implantable antenna using a classic channel model and a simplified dynamic human phantom. The bit error rate (BER) of a single dipole antenna was compared with that of a multi-antenna system employing signal processing techniques, such as maximum ratio combination (MRC) and selection diversity.

II. ANALYTICAL MODEL, METHOD, AND RESULTS

Figure 1 illustrates the EM and channel models used to analyze the implanted dipole antennas, taking into account multipath components with the dynamic arm-swinging motion of the human body [8]. The antennas were implanted at a depth of 5 mm beneath the body surface at two locations: the waist and the wrist. The human body was modeled as a homogeneous configuration with muscle tissue properties, operating at a frequency of 950 MHz.

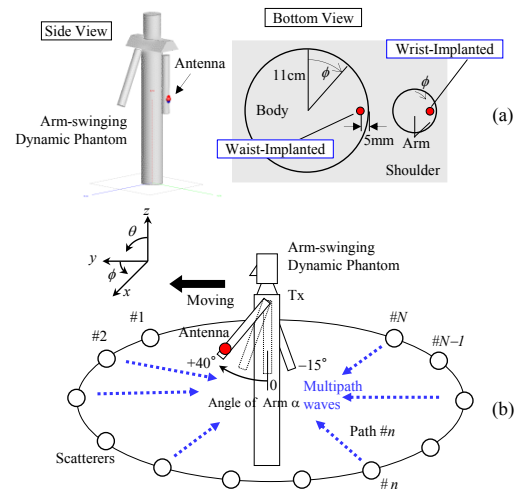


Figure 1. Analytical model. (a) EM-simulation. (b) Channel simulation.

Figure 2 illustrates the instantaneous response resulting from the combined effects of EM interactions with inner tissue, multipath propagation, and arm-swinging shadowing,

with the implanted antenna location as a parameter. The scenario considers a walking distance of 4 steps, equivalent to 16 wavelengths at 950 MHz, assuming a stride length of 70 cm and one arm-swing cycle ranging from 40 to -15 degrees [9] [10]. The cross-polarization ratio (XPR) was set to 6 dB. From Fig. 2, it is evident that the average signal power is significantly degraded due to the low radiation efficiency of implanted antennas, a characteristic distinct from antennas in free space or body-worn devices. Additionally, for a single half-wavelength dipole implanted under the skin at the waist, the shadowing effects caused by arm-swinging can be mitigated by relocating the antenna from the waist to the abdomen (i.e., shifting the angle, ϕ , from 90 to 30 deg.). Moreover, for a dipole antenna implanted under the wrist skin, despite polarization mismatches with the XPR of incoming waves, the overall signal level is higher. Fig. 3 presents the average bit error rate (BER) characteristics of QPSK signals corresponding to the results in Fig. 2. It is observed that the BER degradation for the wrist-implanted antenna is less severe compared to that of waist implantation.

Furthermore, we investigated the BER performance of an implanted two-element dipole array, as shown in Fig. 4, using maximum ratio combining (MRC) and selection diversity to improve the required signal-to-noise ratio (SNR). As illustrated in Fig. 4, an approximately 8-dB degradation in SNR is observed when the implant location is shifted from the waist to the wrist at a $BER = 10^{-3}$. Additionally, MRC provided only a slight improvement in BER performance compared to selection diversity for both waist and wrist implantation scenarios.

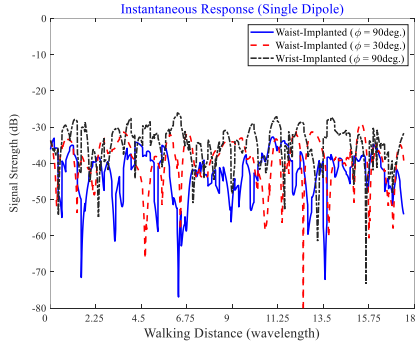


Figure 2. Instantaneous response of implantable channels with the location of implanted dipole antenna as a parameter.

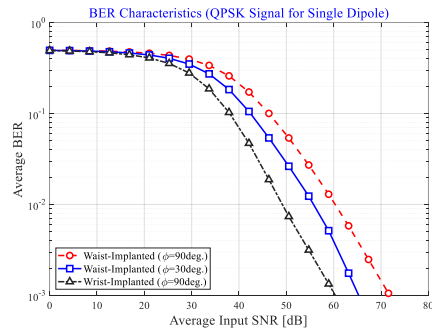


Figure 3. BER characteristics of QPSK signals with the location of implanted dipole antenna as a parameter.

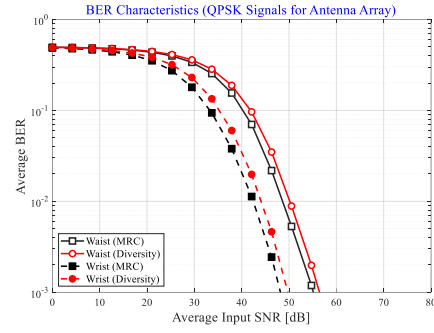


Figure 4. BER characteristics of two-element implanted antenna array.

III. CONCLUSION

In this study, we analyzed the communication quality of a typical implantable antenna in a dynamic WBAN channel. The BER of a single dipole antenna and multi-antenna system employing MRC and selection diversity were shown. The results show that given the burden that implantable devices place on patients, simpler wireless systems are generally more desirable. Therefore, optimizing implant locations may be a more practical approach than relying on the system gain achieved through multi-antenna signal processing.

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