BEAM: Body Coupled Communication Enabled Amplitude Modulation for Skinput application

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Abstract

Body Coupled Communication (BCC) technology has the potential to revolutionise the wearable device field by providing substantial advantages in security, privacy and usability, yet understanding of the factors that influence signal path loss in BCC is crucial for developing accurate measurement techniques and refining the communication system. In this paper a new approach in proposed taking advantage of varying signal loss on touch to enable user input detection and interpretation, it demonstrates high accuracy and reliability. This technology can potentially provide new opportunities for visually impaired or disabled individuals by designating specific body locations as scenario activation triggers and enabling tactile and intuitive interaction with the technological environment. To study the impact of human touch on signal path loss multiple experiments were carried out and the findings enhance the understanding of the factors affecting BCC performance and provides an insight for further research.

1 Introduction

In the fast-paced world of wearable technology, with the escalating demand for secure and effective communication, researchers are being prompted to explore fresh, innovative data transmission techniques. Among these, BCC has emerged as a significant innovation, exploiting the human body as a conduit for transmission. This pioneering technology presents fascinating potential benefits in terms of privacy and usability, specifically in the realm of wearable electronics [15]. Consequently, the technology is finding or has the potential to find its way into diverse application areas such as eHealth [13], personal communication systems [7], human-robot collaboration [2], and more, all of which stand to benefit from the secure and efficient data transmission that BCC potentially offers, especially for multi-sensor wearable systems like shown in papers by Hermanis *et al.* [5, 6]

Recent research has endorsed the viability of BCC for eHealth applications by probing the frequency response of the human body [13], to detect feasible bands for various applications. Nonetheless, understanding the factors that influence signal path loss in BCC is indispensable for the development of accurate measurement techniques and refinement of overall communication system. Unfortunately, lab results, are not 100% applicable to the real-life scenarios, due to multiple factors like: movement artefacts, contaminants on skin surface, susceptibility of surrounding noise etc.

For a comparatively new technology such as BCC it's beneficial to thoroughly express and validate the strengths and weaknesses in comparison to other communication technologies like Bluetooth Low Energy (BLE). This understanding will help BCC find its unique niche, even though BCC Technology readiness level (TRL) is way bellow real-world scenario application. Notably, in radio environments where devices are densely located, like multi-sensor Wireless Body Area Network (WBAN) applications, BLE exhibits limitations [1], which can be seen as an opportunity for BCC to carve out its own distinct position.

In comparison with traditional WBAN technologies, the security aspect of BCC communication is crucial as the signal remains confined within the body, thereby minimising the possible attack surface and consequently the risk of interception and thus enhancing the system's overall security. The physical layer security of BCC is a key advantage over traditional wireless communication methods, protecting personal and sensitive data from potential security breaches.

This paper introduces new use for BCC technology - BCC-Enabled Amplitude Modulation (BEAM), an innovative approach to Skinput-like technology [4]. Typically, Skinput technology uses a piezoelectric sensor to detect the acoustic signal generated by skin taps [4]. BEAM, in contrast, exploits BCC signals that are transmitted between two wearable devices, without interrupting original data transmission between them, in case if BCC devices are using Frequency Modulation (FM) or Phase Modulation (PM). When a user taps on their skin, the signal's amplitude changes, and the BCC receiver detects this alteration. This data enables us to localise the tapping point, transforming those points into potential human input devices, for example, buttons, gesture inputs, or sliders.

Moreover, BEAM's Skinput Human Machine Interface (HMI) capabilities could offer novel opportunities for visually impaired or disabled individuals, by assigning specific body locations to, tailored to individual needs, scenario activation triggers and interacting with surrounding technological environment in a more tactile, intuitive manner. This could promote a new level of independence and comfort, extending the benefits of wearable technology to a wider user base.

The rest of the paper is structured as follows: Section 2 provides the background and introduction of BCC, Section 3 describes the experimental design and taken procedures, Section 4 provides the analysis of the performed experiments, Section 5 discusses the characteristics of BEAM in Skinput applications and the paper is concluded with Section 6.

2 Literature Review

In this section an overview of the key literature related to BCC and its applications is provided. The review covers the following areas: principles and fundamentals of BCC [22], applications of BCC [3], factors affecting BCC performance [16], and experimental methodologies and techniques in BCC research [10].

Principles and Fundamentals of BCC:

BCC leverages the electrical properties of the human body as a medium for data transmission. One of the early works on BCC, by Zimmerman [22], introduced the concept of near-field capacitive coupling, which forms the basis of many BCC systems. Since then, researchers have explored various aspects of BCC, such as channel characteristics, modulation schemes, and coupling mechanisms [3, 16, 18, 20, 17]. These studies have contributed to a better understanding of the underlying principles of BCC and have transformed the design of BCC systems.

Applications of BCC:

As BCC offers secure, efficient, and low-power data transmission, it has attracted interest for various applications. Wearable devices, healthcare monitoring systems, and secure authentication systems are some of the primary areas where BCC has been explored [10]. Studies in these domains have demonstrated the feasibility and benefits of using BCC, including improved privacy, usability, and power efficiency.

Factors Affecting BCC Performance:

The performance of BCC systems is influenced by several factors, such as the coupling mechanism, environmental conditions, body posture, and the presence of other objects in close proximity [10, 12, 21]. Hwang [9, 8] showed that when capacitive coupling is used, at high frequencies radiation from the transceiver node can interfere with the BCC device of another user at distance about 150 cm. Hence, for sensitive data transmission applications galvanic coupling is preferred and this method is investigated in this paper. To the best of authors knowledge, there is no research investigating impact of human touch on BCC path loss, in terms of shorting path length between transmitter and receiver.

Experimental Methodologies and Techniques in BCC Research:

BCC research often involves experimental studies that investigate the performance and characteristics of BCC systems under various conditions. Key aspects of experimental design in BCC research include the choice of measurement techniques, test conditions, and data analysis methods [11, 19]. Guidelines for conducting accurate measurements in BCC studies are provided by [14], the authors also emphasize the importance of understanding the factors that influence signal path loss.

3 Experimental Design and Procedure

This research aims to investigate the variable impacts on signal path loss in BCC systems, primarily induced by human touch at different arm locations. The experimental procedure involves the participant, equipped with a BCC transmitter and receiver attached to their wrists, touching various parts of their arm - the deltoid, elbow, and forearm (as a baseline for experiment, pure, no touch, wrist2wrist signal transmittion were used). To ensure precise and consistent contact points, participants used latex gloves (see Figure 3a), modified with a hole of 2cm diameter in palm location. To further control the contact area, brown duct tape cutouts with square holes (see Figure 3b), each side measuring 1.5cm, were placed on the designated touch areas (see Figure 1). The frequency response was measured at each point, aiming to identify the fluctuations in signal path loss due to palm contact on the specified areas, using a measurement technique outlined in [13]. The test bench consisted of the following parts:

- **BCC Transmitter and Receiver**: Devices used for the BCC signal generation and reception.
- **Electrodes**: Used for signal transmission to and from human skin.
- **Latex Glove with a Hole**: Used to ensure controlled and consistent contact points.
- **Duct Tape Cutouts**: Duct tape with square holes cut out, placed on the designated touch areas to control the contact area.

Experiment Arrangement

Figure 1 provides an illustration of duct tape cutout (see Figure 3b) placements on the participant.

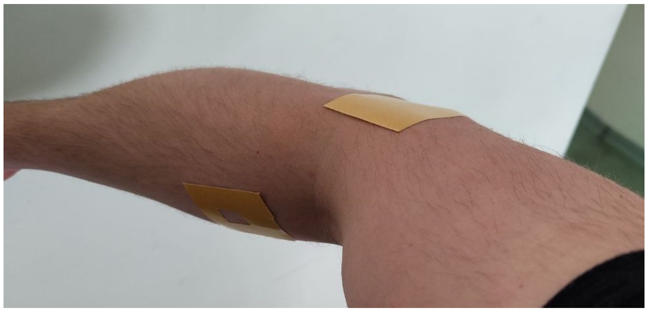


Figure 1: Contact points

Electrode Configuration

This is the 3rd version of EDI reusable, flex-pcb based, electrodes, fabricated with 0.05mm precision and gold-plated (Figure 2). With this type of electrode unit allows to produce stable and repeatable measurements.

Figure 2: The electrode used in the experimental setup.

To hold those electrodes in place, the medical tourniquet was used, as it provided an even pressure on the electrodes and eliminated most of the artefacts caused by participant movements.

Contact Point Surface Control

The latex glove, equipped with a 2cm diameter hole, ensured a standardised and consistent contact area. Figure 3a presents a detailed view of the utilised glove.

The duct tape cutouts, each possessing a square hole with sides of 1.5cm, were placed on designated touch areas, namely the deltoid, elbow, and forearm, to maintain the contact area consistency. Figure 3b provides a visual reference of the cutouts.

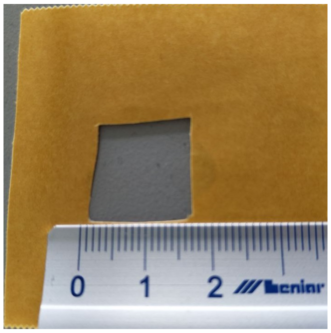
4 Results: Signal Path Loss Analysis

The experiments were conducted to analyze the impact of human touch on signal path loss in BCC systems. The frequency response was measured at each step, as the participant applied their palm to the deltoid, elbow, and forearm. The results obtained from the experiments are presented and discussed in this section.

The signal path loss was analyzed for each touch location, revealing a noticeable change in signal loss when the palm was applied. As illustrated in Figure 4, the signal path loss varied depending on the touch location. The following trends were observed:

- The signal path loss was lower when the palm was applied to the elbow, followed by the deltoid and forearm.
- The difference in signal path loss between the elbow and the other two locations was more pronounced than the difference between the deltoid and forearm.

(a) Latex glove with a hole



(b) Duct tape cutouts with a square hole

Figure 3: Equipment used for controlling the contact point surface

It is important noting the influence of the transmitter and receiver's spatial arrangement on the signal loss. In terms of purposeful path length shortening, one of the most beneficial setup is a wrist-to-wrist arrangement, due to substantial path length change during BEAM usage.

However, this study elucidates how the signal path loss is not only contingent on touch location, but also significantly influenced by the anatomical characteristics of the application point. The potential explanation for such effect could be that such a correlation rises from the differential thicknesses of skin and adipose tissue layers across distinct regions of the arm. Further, it is imperative to note that the relative positioning of the transmitter and receiver, determined by the location of the palm application, distinctly affects the path length the signal has to traverse, hence the acquired signal amplitude.

Clearly, the signal gain decreases when the palm is applied to the elbow as opposed to a similar distance application point, such as the forearm. This can be interpreted in light of the elbow's unique anatomical structure compared to the deltoid and forearm, which, as a bony prominence, is characterised by a lower abundance of muscle and fat tissue. As a consequence, the signal is subjected to less gain, resulting in increased path loss.

5 BEAM Characteristics

The impact of varying signal loss can be leveraged in the context of Skinput applications, where the user's skin serves as an input interface. One approach to describe this effect is

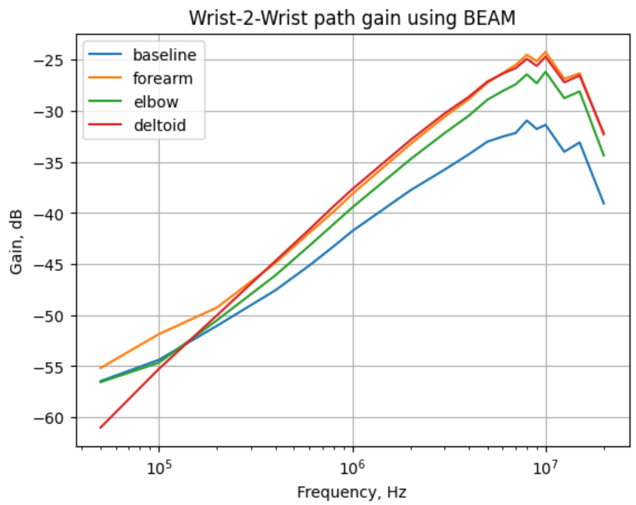


Figure 4: Signal path gain for the deltoid, elbow, and forearm touch locations, baseline - path gain in wrist2wrist setup witout touch

an amplitude modulation that is described with the equation:

$s_t = [A + m_t] * c_t$.

In this abstraction, the variables encompass the parameters of the entire interface.

- The carrier signal, denoted as c_t, signifies a sine wave generated by the transmitter.
- The offset amplitude A is observable when the Skinput interface is not in use.
- Lastly, the modulating signal m_t describes amplitude changes that occur as a result of variations in the signal path.

By employing an amplitude modulation approach, the variations in signal loss can be effectively captured and utilized for Skinput applications. Amplitude modulation involves modulating a carrier wave with the input signal by varying its amplitude in accordance with the changes in the signal strength caused by the different levels of signal loss. This modulation scheme enables the extraction of useful information from the modulated signal, which can then be decoded and processed to interpret the user's input through signal filtering and demodulation. These readings provide data about the user's interactions with the BEAM interface, enabling the system to accurately interpret and respond to the user's input commands or instructions.

The testing of carrier frequency and path loss in shown in Figure 4 and Signal-to-Noise Ratio (SNR) is shown in Figure 5. While using a 1V amplitude input signal within the frequency range of 100kHz to 20MHz, the highest deviation between control points was observed in the range of 5 to 15MHz. This range exhibited significant variations in path loss, indicating potential fluctuations in signal strength and quality.

Furthermore, the highest passband SNR occured at a frequency of 6MHz. This indicates that at this particular frequency, there is an optimal ratio of desired signal to background noise amplitude, resulting in superior signal quality and reliability. Usage of 6MHz frequency provides a balance between path loss considerations and SNR ratio, ensuring the efficient and dependable recognition of different signal paths.

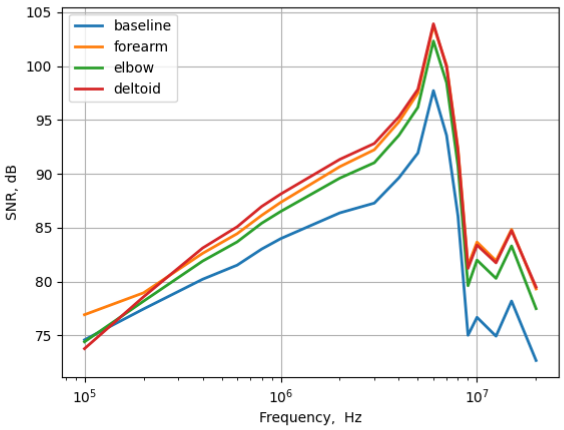


Figure 5: Signal-to-noise ratio for the baseline, deltoid, elbow, and forearm touch locations.

6 Conclusion

In this paper we presented a novel approach to Skinput interfaces that utilizes the human body as a communication channel. The proposed approach leverages the impact of varying signal loss to enable the detection and interpretation of user input. The BEAM interface is capable of detecting and interpreting user input with high accuracy and reliability, while also providing a high degree of sensitivity and robustness.

The described experiments revealed a noticeable change in signal path loss when the palm was applied to different parts of the arm. These findings contribute to a better understanding of the factors that influence BCC performance and can inform the development of strategies to optimize BCC systems in various applications. Not only keeping in mind BEAM application, but also where BEAM effect could be considered as unwanted behaviour.

The technology is still in early development stage and further research is required to improve the performance of the BEAM interface. Future work should focus on improving the accuracy of the system by implementing a more robust signal processing algorithm. Additionally, the system shall be further developed to enable the detection of multiple input points, and decreasing distance between distinguishable points, which could enable the implementation of more complex input commands and gestures.

The potential of BCC technology extends far beyond simple data transmission, as it creates a new paradigm in secure, efficient, and inclusive communication, laying the groundwork for the future of wearable technologies.

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