Measurement and Investigation of HB-UWB Transmission Link for BAN System

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Abstract

The short-range wireless multimedia is consider used a ultra wideband (UWB) technology for human body mobile and multimedia applications shows promise for wireless multi-media systems. Based on IEEE 802.15.6, wireless body area networks (BAN) require understanding the human body's effects on channel characteristics. This paper presents how to evaluation of human body ulra-wideband (HB-UWB) transmission with line-of-sight and non-line-of-sight scenario. Our research aims to enhance HB-UWB channel propagation on the body media by employing with CLEAN algorithm to eliminate noise. This research leverage findings from previous studies to facilitate performance comparison. Furthermore, for analyze system performance using the CLEAN algorithm at different body positions. The measurement setup covers band the FCC regulated from 3.0 GHz to 11 GHz. It includes the tested with wideband antenna and vector network

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analyzer (VNA). HB-UWB characteristics are shows in the path loss and power delay profile are discussed as relevant parameters. This research very useful for design and evaluation of human body mobile network and wireless multimedia systems.

Keywords: UWB, HB-UWB, WBAN, wireless multimedia system, CLEAN algorithm.

1 Introduction

Ultra-wideband (UWB) is wireless multimedia technology has gained significant recognition in modern short range wireless multimedia systems due to its advantages, including low energy consumption, big data transmission multimedia system, low transmitted power, and anti-multipath capability [1–5]. UWB is big bandwidth particularly suitable for in an indoor media environment such as wireless personal multimedia and body area multimedia, as it helps minimize noise interference from other coexisting wireless systems. UWB communication utilizes a unique pulse-based approach with low power spectrum density and compact pulse shapes, enabling transmission over a wide bandwidth instead of a narrow frequency band typically used in other wireless multimedia technologies. The UWB big frequency spectrum, regulated by the FCC, spans from 3.1 GHz to 10.6 GHz, with a minimum bandwidth of 500 MHz, the best for multimedia technology.

Wireless body area networks (WBANs) have emerged as a prominent and dynamic area of research within short-range wireless multimedia systems. These networks are designed to facilitate seamless and unobtrusive communication within a limited range of 1–5 meters around the human body, opening various applications and possibilities [6].

WBANs encompass various domains, with healthcare and non-healthcare applications being the primary focus. Healthcare applications of WBANs prioritize reliability and accuracy in monitoring and diagnostic capabilities. These applications play a crucial role in medical settings, enabling continuous monitoring of vital signs, remote patient monitoring, and early detection of health issues. To meet the stringent requirements of healthcare applications, WBANs in this domain emphasize factors such as emitted power control, power consumption optimization, and robustness in wireless transmission [7].

On the other hand, non-healthcare applications of WBANs are geared towards providing high-speed data transfer, primarily for entertainment.

These applications cater to augmented reality gaming, virtual reality experiences, and multimedia streaming. WBANs aim to deliver maximum data rates in these scenarios, ensuring a seamless and immersive user experience. Achieving high throughput and low latency becomes a priority, allowing users to enjoy real-time interactions and multimedia content without any perceivable delay [8].

Another aspect that distinguishes WBANs is the mode of application deployment, which can be categorized as wearable or implantable. Wearable WBANs consist of devices that are externally worn by individuals, such as smartwatches, fitness trackers, or sensor-equipped clothing. These devices provide continuous monitoring, activity tracking, and personalized health feedback. On the other hand, implantable WBANs involve the insertion of tiny sensors or devices within the human body, enabling real-time monitoring of vital signs, drug delivery, and localized treatment. Both wearable and implantable WBANs come with their challenges and considerations, such as device miniaturization, power management, data transmission efficiency, and ensuring compatibility with human body [9].

The research landscape of WBANs is expansive and encompasses various areas of investigation. These include signal propagation within the body, interference mitigation techniques, energy-efficient communication protocols, security and privacy measures, and data reliability. Researchers strive to address these challenges and develop innovative solutions to enhance the performance and capabilities of WBANs multimedia [10–13].

This paper presents an HB-UWB transmission waveform for WBAN systems, considering both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios. In the LOS case, a biconical antenna serves as the transmitter. In contrast, a microstrip patch antenna is placed before the human body to act as the receiver. Conversely, in the NLOS scenario, the receiver is positioned behind the human body with LOS and NLOS are employed to examine the impact of the human body on BAN communication. The transmission channel utilizes an extended version of Friis' formula for UWB signals. It operates within the frequency range of 3.1 GHz to 10.6 GHz, as the FCC regulates. This study demonstrates the practicality of HB-UWB transmission measurement and its implications in the presence of a WBAN multimedia systems.

Initially developed for radio astronomy and microwave communication, the CLEAN algorithm has found extensive application in both narrowband and UWB communication, including localization and UWB biomedical imaging [14]. It involves cancelling similarities between a dirty map (measurement) and a template (a priori information) to reconstruct a clean map (CIR). However, CLEAN assumes a non-dispersive channel, where the resulting CIR is a sum of amplitude-scaled and time-shifted versions of the a priori information. This assumption must be carefully considered when probing the channel with sub-nanosecond impulses in UWB time-domain channel sounding [15]. Due to the wide spectral occupancy of UWB pulses and numerous objects in the channel, the received signal is severely distorted, primarily in frequency-selective propagation phenomena caused by object materials, orientations, and shapes. This distortion is particularly pronounced in non-line-of-sight (NLOS) and long-range line-of-sight (LOS) measurements [16].

This paper aims to improve UWB channel propagation on the human body using the CLEAN algorithm and compare it with the case without using it. The CLEAN algorithm is applied to UWB localization and HB-UWB, enhancing the performance of channel propagation for communication systems and medical applications. By reducing noise in UWB channel propagation, the CLEAN algorithm helps estimate the directional signal and channel propagation more effectively. In this paper, we build a new channel impulse response (CIR) or CLEAN map based on the original data.

The subsequent sections of this paper are organized as follows: Section 2 explains the HB-UWB transmission loss. Setup of measurement setup and parameters are described in Section 3. Section 4 discussion and results of research. Finally, the concludes of research with key findings.

2 Waveform Transmission Analysis

In conventional wireless short-range system, when examining the propagation of signals in unobstructed, free space, it is customary to utilize the widely adopted Friis' transmission equation. This equation is valuable for analyzing the link budget, particularly in line-of-sight scenarios. To shed light on the specifics of the transmission process in the context of our research, we present a comprehensive illustration of the waveform transmission analysis in Figure 1. This model encapsulates the key elements and parameters involved in the transmission, allowing for a better understanding and evaluation of the system's performance.

$$G_{\mathrm{Friis}}(f) = \frac{P_{\mathrm{r}}(f)}{P_{\mathrm{t}}(f)} = G_{\mathrm{f}}(f)G_{\mathrm{r}}(f)G_{\mathrm{t}}(f) \tag{1}$$

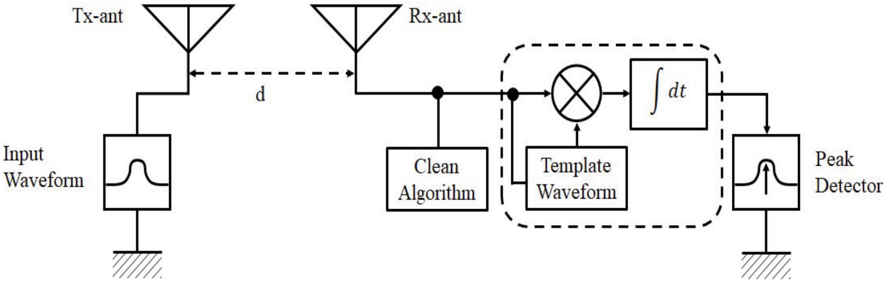

Figure 1 The waveform transmission analysis for HB-UWB multimedia system.

In this study, it is essential to explore the intricacies of the antenna system and the associated parameters. The transmitted antenna input power is represented as $P_{\mathrm{t}}(f)$, symbolizing the magnitude of the signal being transmitted. On the receiving end, we have the received antenna output power denoted as $P_{\mathrm{r}}(f)$, which captures the strength of the received signal. Furthermore, we consider the received antenna gain, denoted as $G_{\mathrm{r}}(f)$, and the transmitted antenna gain, denoted as $G_{\mathrm{t}}(f)$, both of which play significant roles in shaping the overall signal characteristics.

$$G_{\mathrm{f}}(f) = \frac{P_{\mathrm{r}}(f)}{P_{\mathrm{t}}(f)} \tag{2}$$

In the examining of propagation dynamic of free space loss, to determining the propagation channel gain, denoted as $G_{\mathrm{f}}(f)$. This gain represents the amplification or attenuation experienced by the signal as it propagates through space. It can be mathematically expressed as the ratio of the received antenna output power $P_{\mathrm{r}}(f)$ to the transmitter antenna power input $P_{\mathrm{t}}(f)$. Considering factors such as wavelength (λ), the velocity of light (c), the working frequency (f), and the distance maximum (d) between the transmitter and receiver antennas, the free space transmission gain can be calculated.

Expanding upon the classical Friis transmission equation, in the extend to analysis to incorporate the system transfer function [7]. This extension allows us to gain deeper insights into the behaviour and characteristics of the transmission system under consideration. By considering the system transfer function, it can be more comprehensively understand the signal propagation and its impact on the overall system performance.

$$H_{\text{e-Friis}}(f) = \frac{V_{\mathrm{r}}(f)}{E_{\mathrm{i}}} = H_{\mathrm{f}}(f)H_{\mathrm{i}}(f)\mathbf{H}_{\mathrm{r}}(f) \cdot \mathbf{H}_{\mathrm{t}}(f) \tag{3}$$

where

$$\mathrm{H_f}(f,d) = \frac{\lambda}{4\pi d}\exp(-jkd) \tag{4}$$

is the free space transfer function of wireless communications, when

$$k = \frac{2\pi}{\lambda} \tag{5}$$

is the constant of free space propagation, $H_\mathrm{i}(f)$ is transmitted signal filter, $\mathbf{H}_\mathrm{t}(f)$ and $\mathbf{H}_\mathrm{r}(f)$ are transfer function of transmitted antenna and transfer function of received antenna, respectively.

The profile of power delay model means the relative power of the taps for the wireless propagation loss. It provides the characteristic delay as the variant value of mean power as expressed as

$$\overline{\tau} = \frac{\sum_{i=1}^{n} a^2\tau_i}{\sum_{i=1}^{n} a_i^2} = \frac{\sum_{i=1}^{n} P(\tau_i)\tau_i}{\sum_{i=1}^{n} P(\tau_i)} \tag{6}$$

with $\overline{\tau}$ is mean excess delay, a_i is signal level of path i, $P(\tau_i)$ is power level of signal path i and τ_i is time delay of signal path i.

The HB-UWB transmission loss given the relationship between of the peak maximum value of waveform transmitted and waveform received.

$$P_\mathrm{UWB}(dB) = 20\log\left[\frac{\max|v_\mathrm{t}(t)|}{\max|v_\mathrm{r}(t)|}\right] \tag{7}$$

$$v_\mathrm{t}(t) = \int_{-\infty}^{\infty} \mathrm{H_t}(f)e^{j2\pi f_\mathrm{c}t}dt \tag{8}$$

$$v_\mathrm{r}(t) = \int_{-\infty}^{\infty} \mathrm{H_r}(f)e^{j2\pi f_\mathrm{c}t}dt \tag{9}$$

with the transmitted waveform is $v_\mathrm{t}(t)$ and the received waveform is $v_\mathrm{r}(t)$.

2.1 CLEAN Algorithm

In this paper, to explore an innovative application of the CLEAN algorithm to address the unique challenges and intricacies for the HB-UWB (Human Body Ultra-Wideband) characterization. While the CLEAN algorithm has previously found success in localization tasks [14], our primary objective lies in harnessing its potential within the domain of HB-UWB, where the aim is to enhance signal quality by effectively mitigating noise and reducing signal distortion. By leveraging the inherent capabilities of the CLEAN algorithm, we endeavour to refine and optimize the performance of HB-UWB multimedia communication systems, opening new frontiers for advancements in wireless multimedia.

Although the basic framework of the CLEAN algorithm for narrowband channel processing was initially introduced in [15], catering to the precise estimation of time of arrival (ToA) details through the ingenious application of image processing techniques, our research takes a bold step forward by expanding its functionality to cater specifically to the demands and intricacies of HB-UWB scenarios. By adapting and tailoring the CLEAN algorithm to the unique characteristics of HB-UWB multimedia signals, we aim to unlock its full potential for noise reduction and signal enhancement, ultimately ensuring seamless and reliable communication in complex propagation environments.

Implementing the CLEAN algorithm for HB-UWB entails a sophisticated and meticulous series of computations, with a critical focus on the correlation coefficient function. This pivotal component serves as the backbone of the algorithm, enabling the identification and isolation of unwanted noise components, which can severely hamper signal quality. By adeptly removing these undesirable noise elements and reconstructing the underlying signals, the CLEAN algorithm showcases its prowess in restoring clarity and fidelity to the received signals [16].

To provide a visual representation of the efficacy of our proposed approach, we present Figure 2, which elucidates the intricate process of signal cleanup and restoration. This illustrative depiction shows the algorithm's ability to enhance signal quality, fostering reliable and robust communication in HB-UWB scenarios.

However, it is imperative to emphasize that while these algorithms demonstrate remarkable accuracy in estimating channel characteristics, a cautious approach is warranted when interpreting their outputs, particularly the channel impulse response (CIR). As with any modeling-based approach, it is crucial to acknowledge and consider the inherent limitations and potential disparities between the modeled assumptions and the real-world conditions. By maintaining a keen awareness of these factors, researchers and practitioners can make well-informed decisions and extract meaningful insights from the generated CIR data, ensuring the effective deployment and optimization of HB-UWB multimedia systems.

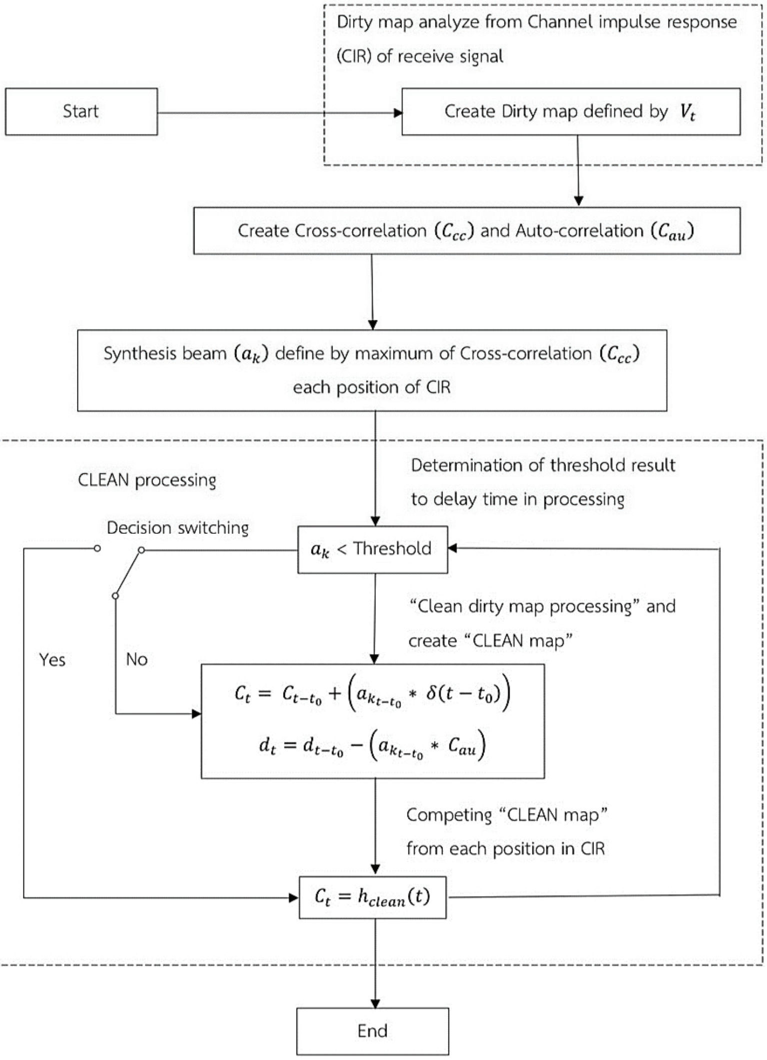

Figure 2 Flowchart of HB-UWB transmission analysis with CLEAN algorithm.

3 HB-UWB Measurement Preparations

3.1 The Transmitted Waveform of HB-UWB System

To comply with the FCC standard for wireless UWB multimedia systems in WBAN multimedia applications, the transmitted waveforms for HB-UWB are designed using rectangular passbands. This choice ensures compliance with the required bandwidth from 3.1 GHz to 10.6 GHz. In the time domain, the waveform's impulse response is characterized by Equation (10). In contrast, its power spectral density in the frequency domain is determined by Equation (11). By utilizing these equations, we can effectively shape and define the HB-UWB waveforms, enabling reliable and efficient communication within designated bandwidth.

$$v_{\mathrm{t}}(t) = \frac{1}{f_{\mathrm{b}}}[f_{\max} \sin\mathrm{c}(2f_{\max}t) - f_{\min}\sin\mathrm{c}(2f_{\min}t)] \tag{10}$$

$$V_{\mathrm{t}}(f) = \begin{cases} \dfrac{A}{2f_{\mathrm{b}}} & ||f| - f_{\mathrm{c}}| \leq \dfrac{f_{\mathrm{b}}}{2} \\ 0 & ||f| - f_{c}| > \dfrac{f_{\mathrm{b}}}{2} \end{cases} \tag{11}$$

The bandwidth of frequency is f_{b}, center of frequency is f_{c}, frequency high is $f_{\max}$, and frequency low is $f_{\min}$, and amplitude is A. These parameters represent the ideal scenario in which HB-UWB transfer function are employed, maximizing the available bandwidth, power, and average amplitude of the waveform transmitted. The waveform of the transmitted of system model is illustrated in Figures 3 and 4, providing a visual representation of the signal characteristics in the research.

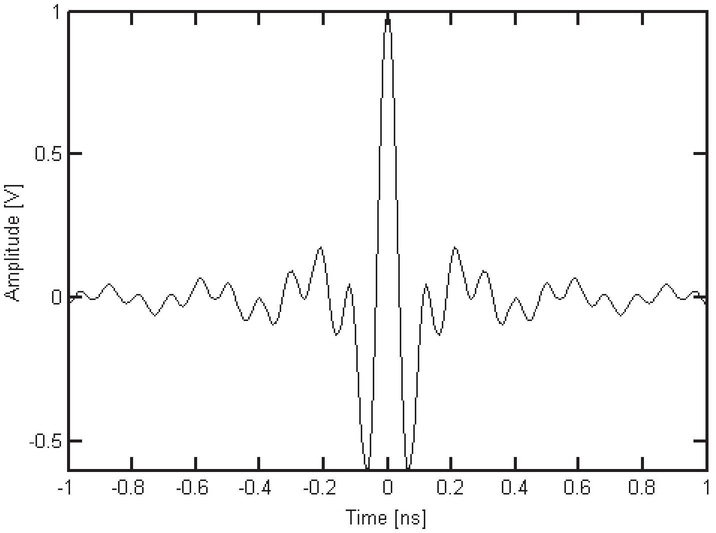

Figure 3 The transmitted waveform for HB-UWB multimedia systems.

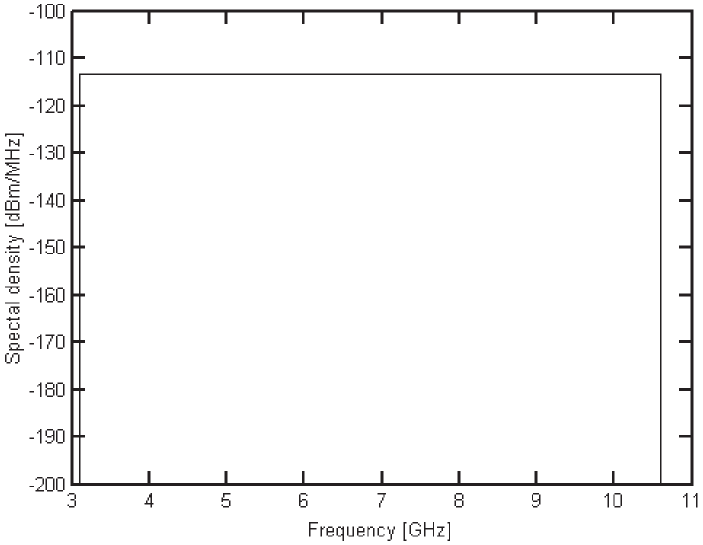

Figure 4 The transmitted spectrum for HB-UWB multimedia systems.

3.2 HB-UWB Measurement Setup

Utilizing a vector network analyzer is pivotal in facilitating the measurement and collection of valuable data for this research endeavour. In the sophisticated capabilities, the vector network analyzer is a fundamental tool for capturing and analyzing the complex characteristics of the channel transfer function. This transfer function emerges as a product of the transmitted and received antenna transfer functions, providing insights into the intricate dynamics of the communication system.

To ensure the accuracy and reliability of the measurements, a well-defined and meticulously designed measurement model and setup have been devised. These models, presented in the illustrative Figures 5 and 6, encompass both line-of-sight (LOS) and non-line-of-sight (NLOS) scenarios, offering a comprehensive understanding of the channel behaviour in diverse propagation conditions.

The experimental setup entails strategically placing the received antenna on the human body in ten locations. This deliberate positioning enables a thorough examination of the impact of different body parts on wireless communication performance. By systematically varying the placement of the received antenna, the research aims to discern the intricate interplay between the human body and the wireless transmission system.

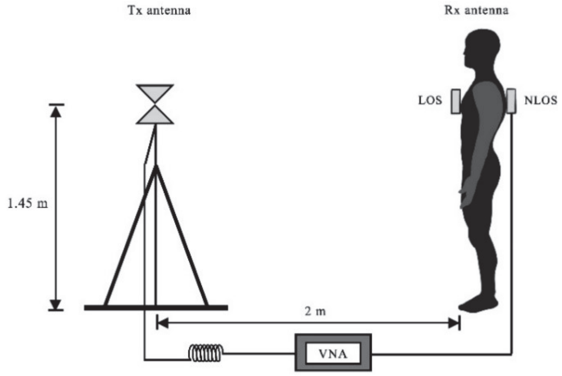

Figure 5 The measurement configuration for HB-UWB multimedia system.

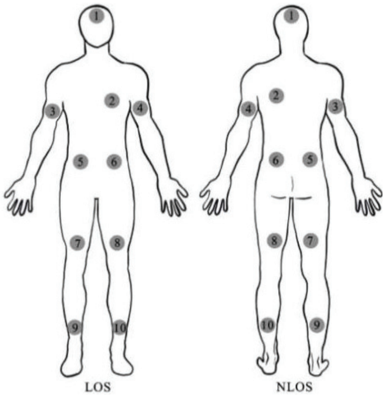

Figure 6 The received antenna orientation with human body of LOS and NLOS.

Furthermore, the transmitted and received antennas are meticulously oriented toward each other, ensuring optimal signal reception and transmission. This configuration fosters a controlled and well-defined experimental environment, allowing for precise measurements and accurate analysis of the channel characteristics.

It is worth noting that the separation distance between the transmitted and received antennas has been intentionally set to 2 meters. This distance is chosen to balance capturing the near-field effects, which are prominent in short-range wireless multimedia systems and maintaining an adequate distance to minimize interference and maintain signal integrity.

Through this comprehensive measurement model and setup, this research seeks to unravel the intricate nuances of wireless communication in the

Table 1 Parameters of HB-UWB measurements

Parameters	Values
Frequency Range (GHz)	3 – 11
Number of Frequency Points	801
Transmitter Antenna Type	Biconical
Receiver Antenna Type	Minder line
Transmitter Height (cm)	145
Receiver Height Range (cm)	15 – 165
Body height (cm)	165
Separate of Tx and Rx antennas (cm)	200

context of the human body. By meticulously investigating the effects of different body locations and propagation scenarios, valuable insights will be gained, paving the way for improved wireless system designs and efficient utilization of the electromagnetic spectrum.

Table 1 in this research manuscript contains important parameters for HB-UWB measurement. It includes the calibration kit components (connectors, cables, and antennas) used with the vector network analyzer (VNA). Additionally, the table lists the characteristics of the transmitted and received antennas based on their respective structures.

4 The Measurement Results

Figure 7 comprehensively analyzes the path loss characteristics in HB-UWB multimedia channels under various conditions, namely free space, line-of-sight (LOS), and non-line-of-sight (NLOS). The results obtained from this study reveal interesting insights into the behaviours of path loss as a distance function. Notably, it is observed that path loss increases consistently with the increase in distance across all scenarios.

A similar path loss trend is observed in free space and LOS, indicating a proportional relationship between distance and signal attenuation. However, the NLOS scenario exhibits significantly higher path loss compared to free space and LOS. This can be attributed to the additional obstacles and propagation challenges encountered by the signal in NLOS conditions, such as reflections, diffractions, and obstructions caused by buildings or other objects.

Power delay profiles are analyzed and presented in Figures 8, 9, and 10 further to understand the impact of these different channel conditions. These profiles provide valuable insights into the distribution of power received as

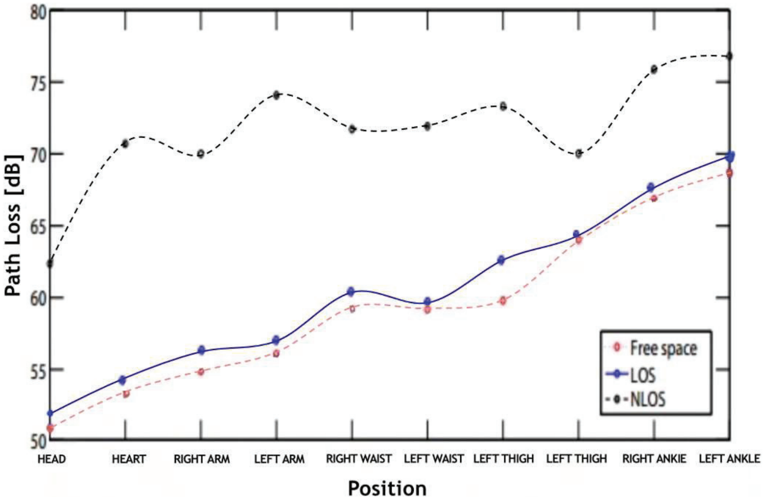

Figure 7 Path loss of HB-UWB multimedia transmission with free space, LOS and NLOS.

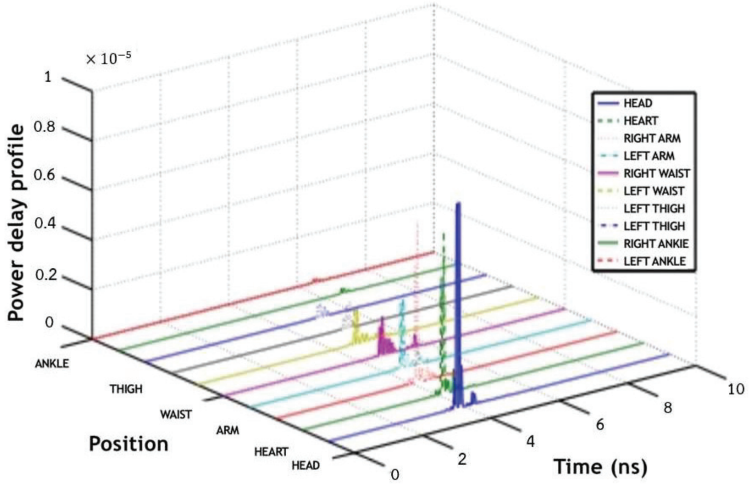

Figure 8 HB-UWB transmission delay with free space case.

a function of time and position. The analysis reveals distinct characteristics for each scenario. In the case of free space, the power delay profile exhibits a relatively uniform distribution, indicating consistent signal propagation without significant distortions or delays. On the other hand, the LOS power delay profile shows some variations and fluctuations, suggesting the influence of direct signal paths and potential multipath components due to reflections.

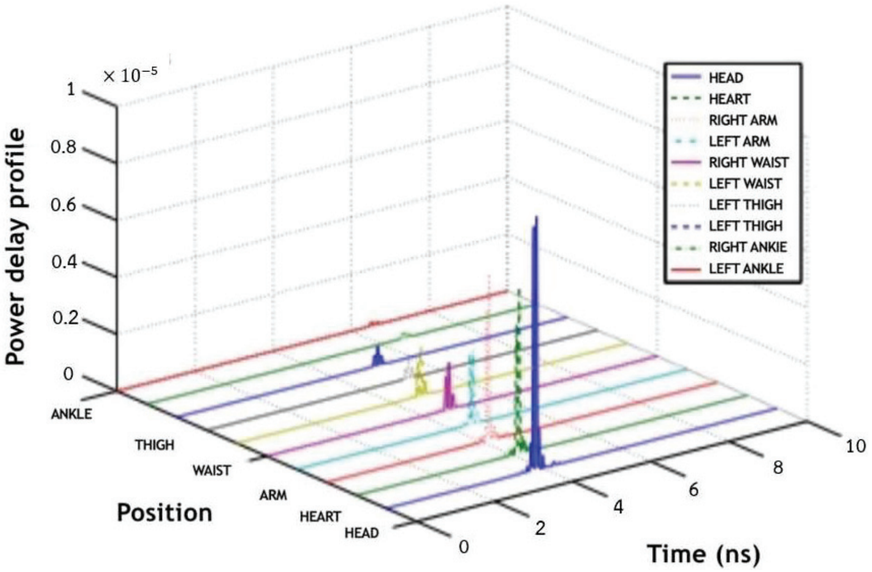

Figure 9 HB-UWB transmission delay with LOS case.

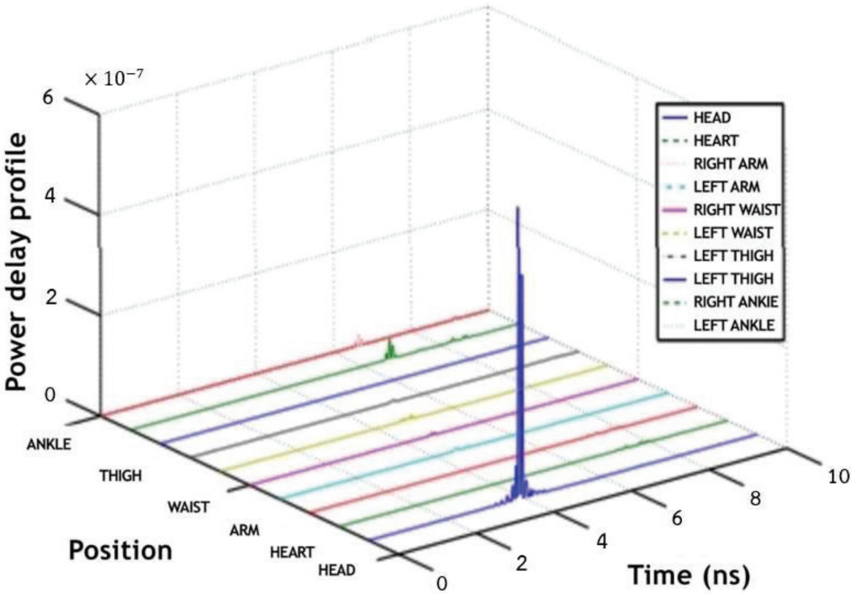

Figure 10 HB-UWB transmission delay with NLOS case.

In contrast, the NLOS power delay profile exhibits a noticeable reduction in the magnitude of the power distribution. This can be attributed to the increased path loss and additional signal attenuation mechanisms introduced by obstacles and environmental factors in the NLOS propagation environment.

It is important to note that the human body and shadowing effects play crucial roles in HB-UWB channel characteristics. These factors introduce additional complexities and signal distortions that must be carefully considered. Understanding the transmission behavior, antenna radiation patterns, and signal levels in HB-UWB systems is essential for accurate channel characterization and effective multimedia system design.

5 Conclusions

This research holds significant value in a wireless multimedia communication technology and has several notable contributions. By evaluating the HB-UWB transmission waveform in both LOS and NLOS scenarios within WBAN multimedia systems, to have gained valuable insights into the effects of the human body on wireless multimedia communications. One of the key benefits of this research is the improved understanding of the multimedia channel characteristics and performance limitations associated with HB-UWB multimedia communication in the presence of the human body media. By analyzing the channel transfer function, path loss, and power delay profile, to provided valuable data and measurements that can be used to optimize the design and deployment of HB-UWB multimedia communication systems. The findings from this research also emphasize the importance of considering the selective channel and shadowing effects caused by the human body. By incorporating this knowledge into the development of HB-UWB receivers and communication protocols, it is possible to enhance the reliability and performance of wireless multimedia communication in WBAN systems, particularly in NLOS scenarios.

Furthermore, this research highlights the need for specialized deployment strategies for HB-UWB transmission in WBAN multimedia systems. By considering the unique channel characteristics influenced by the human body, system designers and engineers can develop tailored approaches that mitigate the impact of shadowing and ensure strong communication links. The contributions of this research extend beyond theoretical knowledge and provide practical insights that can be applied in real-world scenarios. By addressing the challenges and limitations associated with HB-UWB multimedia, have a way for advancements in wireless healthcare monitoring, wearable technologies, and other applications where WBAN multimedia systems play a crucial role.

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Biographies

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Sathaporn Promwong received a Ph.D. in communications and integrated systems from the Tokyo Institute of Technology (TIT), Japan. He is a faculty member at KMITL's Department of Telecommunication Engineering. His expertise spans partial discharge, antenna and wave propagation, wireless channel measurement, digital broadcasting, and WiMedia. He holds leadership positions in IEEE, IEICE, and serves as the chair of the IEEE Broadcast Technology Society (BTS) Thailand chapter.

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