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A Study and Analysis of Channel Modeling for the Ultra Wide Band Wireless Body Area Network

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Abstract— Future Communication systems will be driven by the concept that how every one can be connected from any where at any time. An essential part of this concept is Wireless Body Area Network (WBAN) approach by which services are constantly available and the best use of this WBAN is health monitoring. Indeed, if medical monitoring can be performed wirelessly, the patient is no longer constrained in his movements. But, the successful monitoring depends on the proper channel modeling. This channel modeling requires various consideration as human body has complex and different shapes with different tissues. In this paper, a literature survey and investigation is done for the proper channel modeling, which is suitable for the Ultra Wide Band (UWB) WBAN for the indoor environment. Here, large scale fading as well as small scale fading are analyzed for this consideration. This is found that the lognormal distribution is a good approximation rather than the traditional Rayleigh and Ricean models. On the other hand, the parameters of Nakagami distribution is a good approximation for the small-scale amplitude, as the parameters of Nakagami distribution change with increasing excess delay, while the Gaussian distribution is proposed for mathematical convenience.

Index Terms— Channel Modeling, Path Loss, Wireless Body Area Network (WBAN).

1 INTRODUCTION

Body Area Network is formally defined by IEEE 802.15 as, “a communication standard, optimized for low power devices and operation on, in or around the human body to serve a variety of applications including medical, consumer electronics or personal entertainment and other.” Wireless sensor networks (WSNs) represent a relatively new technology used in the surgical and intensive care units of hospitals, where medical sensors (motes) are routinely attached to the patient by invasive or noninvasive routes. This enables the continuous monitoring of the patient’s physiological variables with enhanced mobility for both the patient and hospital staff. Research in medical WSNs has gained much interest in the last few years and some solutions based on short-range radio communication have been demonstrated [1]-[3]. The IEEE 802.15.4 standard (ZigBee) has been used in most of the cases for the radio interface between medical sensors (motes) and a personal server (PS). The PS either processes the sensed information and displays it through a graphical or audio interface to the user, or transmits it to a broader telemedicine system. This WSN is the core part of any telemedicine.

One of the main disadvantages of IEEE 802.15.4 systems for medical applications is their high vulnerability to interference from IEEE 802.11 wireless local area networks (WLANs) [8] and IEEE 802.15.1 (Bluetooth) transmitters [3]. Hence, interference mitigation techniques for IEEE 802.15.4 have to be implemented before deployment of medical WSNs based on this standard. In fact, both Zigbee and Bluetooth technologies have major constraints to support network topologies consisting of multiple medical sensors [10]. Moreover both of this technology support low data rate communications only, typically below 1 Mbps which is not suitable interfaces for novel applications such as wireless medical imaging.

Ultra Wide Band (UWB) technology has emerged as a solution for the wireless interface between medical sensors and PS in future telemedicine systems [3], [4]. Now a days Ultra Wide Band (UWB) wireless communication offers a radical different approach to wireless communication compared to the conventional narrowband system. Because this technology eliminate most of the drawbacks mentioned above. Ultra wide band communication is a low-power, high data rate technology with large bandwidth signals that provide robustness to jamming and have low probability of detection [1], [2]. UWB technology helps to protect the transmission of patients’ sensitive data by reducing the probability of detection. This might rescind the need for encryption algorithms in medical sensors, which results in lower complexity of the electronics and smaller size of the devices. Additionally, UWB signals do not cause significant interference to other systems operating in the vicinity and do not represent a threat to patients’ safety [3].

2 CHANNELS IN WIRELESS MEDICAL TECHNOLOGY

The channels in wireless medical communications can be divided into two main links [5], i.e. the part one (WBAN

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part): the channels among the sensor nodes and the channels from the sensor nodes on / in the body to the gateway, which can be either on the wall of the hospital room or on the body in the case when the patients walk outside the building (can be a wrist watch or in a bag), and the part two: the channel between the gateway and the access point. On the other hand Depending on their operation environment, three basic types of UWB medical sensors are identified: on-body, in-body, and external [3].The first ones operate on or in very close proximity to the patient's skin (typically less than 2 centimeters), the second ones operate inside the body, whereas the third ones are not in contact with human skin (typically between 2 centimeters and up to 5 meters away).

3 Measurements Techniques

Most of the measurements are performed in the frequency domain method, because it is easy to calibrate and it has dynamic effect [5], [11]. For this, Vector Network Analyzer (VNA) is commonly used for the measurement and experimental analysis of the channels measurements. VNA is set on the response mode in the experimental range (such as 2 GHz-6 GHz) for UWB on-body communication channels measurement. Port-1 is used as a transmit node and Port -2 as the receiver with two pairs of different UWB antennas to measure channel frequency response. Antennas are connected to the VNA by 3 and 5 meter long cables. The VNA measures the magnitude and phase of each frequency components allowing the ease of obtaining the time domain response by means of Inverse Discrete Fourier Transform (IDFT). Two or more than two sets of measurements can be performed in the anechoic chamber to account for deterministic channel characteristics on human body.

In addition, the Remcom Finite Difference Time Domain (FDTD) Simulator [5], [6], [7] is used to model electromagnetic field propagation around the human body. An anatomical and a theoretical model of a body was provided by the visual Human project of the National Library of Medicine [5], [9]. Using this model of the body and FDTD technique the Maxwell's equations can be solved by using finite difference approximations to the spatial and temporal derivatives found in the equations [6], [7].

4 Path Loss Model and Channel Characterization

4.1 Path Loss

The Path Loss (PL), which represents signal attenuation as a positive quantity measured in dB, is defined as the difference (in dB) between the effective transmitted power and the received power, and may or may not include the effect of the antenna gain [10]. Path Loss (PL) arises from the propagating wavefront's increasing surface area as the wavefront radiates outward from the transmitting antenna and the obstructive effects of objects distributed between transmitter and receiver antennas such as free space loss, refraction, reflection, diffraction, clutter, aperture-medium coupling loss and absorption [11].

The path loss of a UWB channel is a function of frequency as well as of distance and can be expressed by a product of the terms [5], [11]. i.e.

$$PL(f,d) = PL(f)PL(d) \text{ .... (1)}$$

The frequency dependence of the path loss is given as [5] is

$$\sqrt{PL(f)} \propto f^{\mathrm{k}} \text{ .... (2)}$$

Where, k denotes the frequency dependence factor determined by the geometric configurations of the objects. The distance dependence of the path loss in dB is written as [11],

$$\overline{PL(d)} = \overline{PL_0} + 10n\log_{10}\left(\frac{d}{d_0}\right) + F_A \text{ .... (3)}$$

Where, n is the path-loss exponent that shows the rate at which the path-loss increases with distance, PL_0 the intercept point which is the path-loss at d_0 (a reference distance), d is the transmitter-receiver separation distance and F_A is the floor attenuation factor (FAF). The bars in (3) denote the average values for the same floor measurement and over all transmitter-receiver antennas locations, while maintaining the same transmitter-receiver separation distance. The variations about the average path-loss value in (3) are called shadow fading. The path-loss exponent n depends on the propagation environment. In free space n =2, but if there is obstacle n >2 [10].

4.2 Large –Scale Fading

Large scale fading is explained by the gradual loss of received signal power with transmitter-receiver (T-R) separation distance. In equation (3), the shadowing loss is not included. Including this loss, the large-scale propagation loss can be obtained [10], [11], i.e.

$$PL(d) = \overline{PL(d)} + \chi \text{ .... (4)}$$

The investigation shows that the propagating wave is diffracting around the human body rather than passing through it [5], [6], [7], [13], [14], [15]. The path loss increases with respect to the distance and the path loss exponent (n) around the human body is between 5 and 7.4, which is much higher than that in free space (n =2). However, the exponent along the front of the human body is around 3 [5], [13].

4.3 Small –Scale Fading

'Small-Scale Fading' describes the received signal amplitude / energy's fluctuations over a short duration or in the spatial neighborhood at the moving antenna's nominal location [10], [11]. This definition can be generalized to UWB communications as the constructive and destructive interferences of the multipath components due to a change in the moving antenna location in the order of the sub-spatial width of the transmitted pulse.

The small-scale distribution strongly depends on environment type. Since there are only a small number of multipath components from the diffraction around the body, the lognormal distribution shows a much better fit rather than the traditional Rayleigh and Ricean models [7],[15]. Moreover, there is a significant correlation between delay bins [7]. On the other hand, the Nakagami distribution [16],[17] whose parameters change with increasing excess delay can fit well the small-scale amplitude, while the Gaussian distribution is proposed for mathematical convenience [11].

5 Conclusion

This paper reviewed and analyzed the research work on channel modeling for WBAN for indoor environment. As, human body has a complex shape with different kinds of tissues, it requires special considerations for the channel modeling for WBAN. The propagating wave is diffracting around the human body rather than passing through it. The path loss is very high especially when the receive antenna is placed on the different side than the transmit antenna. So, it is significant that the choice of separation between the antennas (T_X and R_X) affects the results of path loss due to antenna mismatch. It indicates that proper design of the body-aware antenna as well as the considerations of environments could improve system performance.

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