**Performance Analysis of Antenna for On-Body Wireless Communication System**

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**ABSTRACT**

*This work examined the performance analysis of an antenna for on-body wireless communication. Special emphasis was given to antenna design considerations, channel models, etc. It was mentioned that in the design of antennas for on-body wireless communications, the design should take into consideration the frequency and environment where the antenna will be deployed. Antenna height, sensitivity, and radiation pattern must be considered in the design consideration. Pathloss models and statistical fading models were discussed as applied to on-body wireless communications systems. Two different structures, the L-shaped and the I-shaped structures were analyzed. The reflection coefficients were -24.9dB and -22.21dB respectively. Since the lower the reflection coefficient, the better the performance of the antenna, it was therefore shown that the L-shaped antenna structure performs better if used in on-body communication.*

**Keywords:** Pathloss, Antenna, on-body, wireless communication, reflection coefficient, frequency

**1 INTRODUCTION**

A body-centric wireless communication system is rapidly gaining momentum and may become one of the leading aspects of communication soon. This type of communication comprises three closely related types of communication: off-body communication; on-body communication; and in-body communication. The off-body communication is the type of communication existing between a body and an external network. The in-body communication is the type of communication that exists between devices implanted in the body. And on-body communication is the type of communication that exists between wearable devices, that is, devices worn by people. This is illustrated in Figure 1. As was mentioned, there is a rapidly growing interest in the study of body-centric wireless communication. This is especially so in this era of the Internet of Things (IoTs) where many different devices have been manufactured and used in different fields of study like military and defense, healthcare and medicine etc. [1] One important part of wireless communication, including on-body wireless applications, is the antenna. Antennas ensure excellent power transfer between different nodes positioned at different body parts. To use antennas of on-body wireless communications, such antennas must be light in weight and compact to allow for easy integration with clothes and cloth accessories. To avoid adversely affecting antenna performance by the human body, antennas must be designed to operate freely when placed close to any body part, even though such antenna is implanted in a body. The importance of wireless body area networks in communication has brought about the utilization of smart sensors often implanted in human bodies to send and receive information between different persons or things. The smart nodes can carry out different functions like gathering data, transmitting data, processing data, storing data, etc. In wireless body area networks, technology can be used to monitor patients, capture the movement of humans, carry out movement biomedical analysis, and so forth. In many areas, this is called the Internet of Humans (IoHs). Therefore, individuals can readily monitor their fitness and health status using implantable wearable devices.

**1.1 Classification of Body-Centric Wireless Communication**

**1.1.1 On-body wireless communication**

As was mentioned before, on-body communication involves communication using wearable, not implantable, devices or sensors. This means that the antennas for on-body communications are worn on the body and they are suitable for use in the healthcare sector. For wearable devices, radiation issues and SAR values are reduced. Besides, antennas worn on the body are capable of easily undergoing size reduction. Because of the movement of the body, wearable antennas regularly change maximum radiation direction, resulting in reasonable changes in the performance of radio links.



Figure 1: On-body wireless communication

**1.1.2 Off-Body Wireless Communication**

Off-body wireless communication is communication between a wearable device or an implanted device with an external network. The external network could be a base station, a data centre, etc. When a wearable device or sensor gathers data from the person wearing it, it sends the information to another device or to an external network for processing. This communication between such wearable sensors and the external network is known as off-body communication.



Figure 2: Off-body wireless communication

**1.1.3 In-Body Wireless Communications**

Nowadays, miniaturized devices with very small weight and power have been designed to have capabilities for communication wirelessly. These devices can be implanted in the human body and made to communicate with each other or with an external network. When the devices are implanted in the human body, we have in-body communication. When in the body, the devices or sensors gather vital information or data from the body that may require urgent attention by the doctor.

**2 LITERATURE REVIEW**

[11] carried out investigations on  Miniature Planar Inverted-F Antenna for 2.45 GHz On-Body Communications. It was noted that Body-centric wireless communications (BCWC) have recently attracted more interest due to its applications in numerous fields such as E-health systems, home care, and entertainment. A miniature PIFA operating in the ISM band (2.40-2.48 GHz) was proposed for on-body communications.

They came to the conclusion that the antenna architecture used two shorting mechanisms (shorting pin and shorting plate) and a foldable ground plane, resulting in a low profile and miniature antenna. The operational efficiency of the intended antenna was investigated, considering bandwidth, radiation pattern, and gain. Furthermore, the results revealed that the resonating frequencies of the intended antenna in free space and near the phantom were nearly identical.

[12] further conducted research on Wearable dual-band and dual-polarized textile antennae for on- and off-body communications, concluding categorically that implantable antennas used in multiband with polarisation diversity can realise multifunction, such as on- and off-body communications in one gadget with space saving and minimal cost in wireless body-based network (WBAN) systems.

A dual-band wearable MPA with polarisation and radiation variations was proposed. In their investigation, they noted that all the results measured were in accordance with the simulated ones and that the SAR values showed that the proposed antenna met the health and safety requirements. In all, the antenna possesses the advantages of dual bands, dual polarisations, adaptation, and efficient operation, making it an excellent choice for multipurpose wearable gadgets.

Their study [13] looked at Transient characteristics of wearable antennas and radio propagation channels for UWBWC and noted that ultrawideband (UWB) technology is a low-power, high-data-rate technology that provides immunity to multipath interference and has robustness to jamming because of its low probability of detection.A novel miniaturized CPW-fed tapered slot antenna was proposed and used for transient measurements of UWB radio channels for body area network (BAN) and personal area network (PAN) scenarios in their study. In their conclusion, they presented and characterised planar and small UWB antennas in both the spectrum and transient domains. In addition to the return loss and radiation patterns, the transient analysis in free space at various planes and angles was also analysed and explored analytically. The results revealed that both antennas met UWB specifications in terms of impedance, radiation bandwidth, and impulse responses (pulse fidelity), with an average fidelity of 88% and 86% for PICA and TSA, respectively. The fidelity investigation of free space, on-body, and indoor body-centric radio propagation settings revealed that both antennas performed well in maintaining the shape of the receiving pulse at varied angular orientations, resulting in reliable system functionality.

Authors [14] and [15] in their research work investigated the prospective design architecture of wearable antennas to define body-centric wireless communications (BCWC) as any wireless communication on, within, or around the human body that encompasses a broad spectrum of the latest emerging fields such as personal healthcare, personal entertainment, sporting activities, authentication systems, the security, and so on. In their design, two dual-band antennas are proposed with multiple radiation patterns for BCWC and each one of the dual bands has a directional and an omnidirectional radiation pattern at the low and high-frequency bands, respectively. They concluded in their results that both antennas provided reconfigurable omnidirectional directional radiation patterns and are suitable for use in the on/off-body links of BCWC applications. [16, 17, 18, 19] studied different antennas, including implantable antennas.

**3 MATERIALS AND METHOD**

A reasonable number of parameters is required for directing the characteristics of the body area network’s wireless channel application. Therefore, analyzing the various channels is better done with statistical methods. In this case, the output parameter of the channel could be assigned a certain probability level [5]. The channels for body area networks are readily studied, in some cases, in differential scenarios. The channel model for the narrowband considered in this work includes:

1. Fading statistical model
2. Path loss model

**3.1 Fading Statistical Model**

Most often, the immediate environment generates multipath. In the analysis of body area networks, any generated multipath must be considered and never ignored. It should be noted that if the path of the signal between the transmitter and receiver is blocked by the human body or part of the body like the hand or head, then we have body shadowing in the body area network channel. The size of this shadowing depends to a very large extent on the size of the obscuring body part. As was mentioned in [6], the issue associated with body shadowing is mainly pronounced for the developing mmw (millimetre wave) on-body communications carried out at 60GHz. At such frequency, it is argued that the huge shadowing effect due to the human body will make any non-of-sight communications highly difficult.

While some studies have separated the received signal into two different parts: a small-scale component part and a body shadowing component part, other studies never made such separation or decomposition of the received signal. Some studies like [7] have even added a lognormal probability density function (pdf). If the envelope is given by the letter R and the mean is given by the Greek letter $δ $while the standard deviation is denoted by the letter $β$ , then, the lognormal probability density function is given as:

$f\_{R}=\frac{1}{rβ√2π}exp\left(-\frac{[In\left(r\right)-δ}{2β}\right)^{2}$ (1)

In [7], lognormal fading was observed at 2.45GHz in the on-body communications channel, particularly when the object for the test was on the move, was in the restroom, etc. This is quite different in the case of Rayleigh fading where the signal received is as a result of the addition of different signal components scattered, with each component having its own phase and amplitude [5]. Between 915MHz and 2.45GHz Rayleigh fading has been observed [5].

In the channels for on-body communications, there is powerful reflection due to on-body, and there exists a line of sight, in addition to dominant creeping-wave components. As a result of the above, the received signal distribution can be modelled as Rice pdf (probability density function), as can be seen from equation (2).

$f\_{R}=\frac{r}{S^{2}}exp\left(-\frac{r^{2}+c^{2}}{2S^{2}}\right)I\_{o}\left(\frac{rc}{S^{2}}\right)$, r$\geq 0$ (2)

Where c is the dominant component and s is the scattering power.

 **3.2 Path Loss Models**

There is a great difficulty associated with fitting distance-related path loss models to on-body channels obtained data because of the human body geometry, in addition to various trajectories of the signal path. This explains the reason why some researchers like [8] concluded that path loss models are not appropriate for body area network communications. This conclusion notwithstanding, some path loss models for body area networks have been investigated for clearly defined links. In [9] for example, the authors used the free space Friis formula for on-body communication within the frequency of 2,4GHz. The work provided an excellent fit of simulated and measured data with a distance of 0.4m between the receiver and the transmitter.

A model for power law presented in the IEEE802.15.6 document is:

$P\_{dB}=aLog\left(d\right)+b+N$ (3)

The constants a and b are the model parameters while N is a normally distributed variable having a standard deviation of $δ $and d is the distance between the transmitter and the receiver.

A more comprehensive model, a hybrid one that puts the environmental effects like multipath component and local propagation models together. This resulted in a saturation part for wide distances and an exponential part for small distances. This path loss is presented in Equation (4).

$P\_{dB}= -10Log\left(P\_{o}e^{-m\_{o}d}+P\_{1}\right)+δ\_{p}n\_{p}$ (4)

Where d is the distance in centimetres around the body, $P\_{1}$ is the mean attenuation of the components, $m\_{o}$ is the mean exponential decay rate, measured in decibels per meter(dB/m), $n\_{p}$ and $δ\_{p}$ are zero mean and unit Gaussian random variable and lognormal variance, measured in decibels (dB). $P\_{o}$ is a factor that depends on the mean losses within the transmitter.

It is quite true that the large variety of body area network links makes it hard to fit model that depends on single distance to all possible scenarios, but pathloss models that depend on distance have been derived. The derivation has to do with specific scenarios. This pathloss is presented in Equation (5):

$P=P\_{o}+10nLog\left(\frac{d}{d\_{o}}\right)+N$ (5)

N retains the usual meaning, the normally distributed variable having zero mean. The pathloss exponent n is equal to 7.2. [5] reported a work in which the value of n for indoors was 2.7.

**3.3 Antenna Design Considerations for On-Body Wireless Communication**

The design of a body-centric wireless system will be incomplete without antenna considerations. With adequately designed antennas for OBWC, power transfer from and to different nodes can be guaranteed. Some antenna design considerations for OBWC include;

1. Operational frequency
2. Antenna height
3. Antenna sensitivity
4. Antenna radiation pattern
5. Antenna gain

**3.3.1 Operational frequency**

It is understood that the frequency of operation of an antenna can be affected by the environment under which the antenna operates. For example, in [2] it was stated that between the frequency range of 400MHz and 10GHz, antennas suffer from distortion of radiation patterns, experience efficiency and input impedance changes, and suffer detuning if they are positioned close to the human body or on the human body itself. This can affect the performance of the antenna. To avoid this, the design should take into consideration the frequency and environment where the antenna will be deployed.

**3.3.2 Antenna Height**

Since the antennas for BCWC can be on the human body, that is, worn by humans, one key requirement or consideration in the design of such antennas is the size or weight. They must be lightweight to enable easy integration with cloths and cloth accessories worn by humans.

**3.3.3 Antenna sensitivity**

Antennas can be highly sensitive. This enables them to be able to function efficiently. However, antennas that can be worn by humans on the body must be designed in such a way that their sensitivity to the body they are placed close to is low [1].

**3.3.4 Antenna radiation pattern**

[1] noted that the peak radiation pattern for on-body communications ought to be tangent to the surface of the body. This tends to maximize the coupling between devices that are worn on the body. The exception to this, noted [1] is if the radiation pattern of the wearable antennas is outward when the off-body link is being established. Monopole antennas are good for on-body use at low frequencies. However, the gain of monopole antennas is too low compared to what is required at the frequency band of 60GHz. To improve the gain and therefore make monopole antennas useful for on-body communications, metal-material structures can be used.

**3.3.5 Antenna Gain**

[3] presented a measurement carried out using monopole antennas, and stated that human body pathlosses were between 57dB and 88dB based on the link. Therefore, for a reliable link to be established on the human body is really difficult. To overcome this challenge, antennas to be used for BCWC should have high gain so as to increase the signal. [1] suggested a gain of 10dBi at least, both at the receiver and the transmitter.

**4 RESULTS AND DISCUSSION**



Figure 3: Reflection coefficient against frequency for a double I-shaped structure



Figure 4: Reflection coefficient against frequency for a double L-shaped structure

The performance analysis of the antenna for on-body communications is here undertaken. When carrying out antenna measurements, much emphasis must be placed on the S11 parameters since they must fall within the range of the wearable device. If the S11 parameters lie outside the acceptable range, the parameters can be adjusted until a desirable result is obtained. Two different structures, the L-shaped and the I-shaped structures were analyzed. A plot of the reflection coefficient against frequency. The reflection coefficient for the two different structures, the L-shaped and the I-shaped structures, as can be seen from Figures 4 and 5 are -24.9dB and -22.21dB respectively. Since the lower the reflection coefficient, the better the performance of the antenna, it therefore shows that the L-shaped antenna structure performs better if used in on-body communication.

**5 CONCLUSIONS**

The performance analysis of the antenna for on-body wireless communication has been undertaken. Since the antennas for OBWC can be on the human body, that is, worn by humans, one key requirement or consideration in the design of such antennas is the size or weight. They must be lightweight to enable easy integration with cloths and cloth accessories worn by humans.

The reflection coefficient for the two different structures, the L-shaped and the I-shaped structures were found to be -24.9dB and -22.21dB respectively. And since the lower the reflection coefficient, the better the performance of the antenna, it was therefore shown that the L-shaped antenna structure performs better if used in on-body communication.

Antennas can be highly sensitive. This enables them to be able to function efficiently. However, antennas that can be worn by humans on the body must be designed in such a way that their sensitivity to the body they are placed close to is low. For a reliable link to be established on the human body is really difficult. However, the difficulty can be overcome if the antennas to be used for OBWC have high gain to increase the signal. suggested a gain of 10dBi at least, both at the receiver and the transmitter. Monopole antennas are good for on-body use at low frequencies. However, the gain of monopole antennas is too low compared to what is required at the frequency band of 60GHz. To improve the gain and therefore make monopole antennas useful for on-body communications, metal-material structures can be used.

A reasonable number of parameters is required for directing the characteristics of the body area network’s wireless channel application. Therefore, analyzing the various channels is better done with statistical methods. In this case, the output parameter of the channel could be assigned a certain probability level. The channels for body area networks are readily studied, in some cases, in differential scenarios. The channel model for narrowband considered in this work includes the fading statistical model and Path loss model were considered in this work.

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