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STUDY OF CHANNEL MODELS FOR BODY CENTRIC COMMUNICATIONS

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Table of Contents

List of Figures

List of Tables

ABSTRACT

Body centric communication is termed as body to body or within body communication with the help of wearable or implantable wireless devices. It has wide range of application areas like healthcare, military, entertainment and control of smart home appliances. With the advancement in the electronic components and information and communication technologies along with ever decrease in the antenna size has promised development of vast range of devices that can be useful in above mentioned fields especially in medical science. Recent studies carried out on millimetre waves have shown many advantages of making communication systems work in this spectrum of wavelength. Firstly, advantage in the reaching high data rates because of large available spectrum that is 7GHz. Secondly low interference with adjacent networks with high security level. Most importantly size of millimetre wave systems is smaller as compared to systems using microwaves.

The aim of this thesis is to conduct a study on currently available channel models for body area network, but we will also have a look on other type of body centric communication systems. Initially we are going to discuss some of the standardized models presented in the IEEE 802.15.6 and IEEE 802.15.4 standards. After that we will be considering two of the most popular technologies currently being used namely narrowband communications and ultrawideband communications. We will also have a look on the radio channel modelling techniques and their requirements. Finally, we will highlight some newest relevant research in other areas of body centric communication.

1. Introduction

1.1. Background

In recent years body centric communication systems have gained a lot of importance because of their huge application in different fields of science. Basically, body area networks are the wireless communication systems that enables interaction between several body centric applications that can be sometimes worn on the body or can be placed internally in body, or they can close to the human body. Such systems have got huge attention especially in the field of military, healthcare, Identity recognition systems, and operation of smart home appliances.

Body area networks used in the medical sector contain nodes integrated with sensors used for monitoring and improving healthcare. A simple BAN system can be based on mesh topology It can also be a star topology or sometimes combination of both. In mesh star hybrid topology, the data is routed directly towards the destination node without sending it to a coordinator. Basically, a coordinator is present in the network which collect all the data coming from different nodes in the BAN before routing it to main destination node. This destination node can be on body or can be off body to some external network where its further monitor and used for diagnosing or study. A star topology is working with the intervention of coordinator. The star mesh hybrid topology has been considered efficient as all nodes can behave as relays [1]. Moreover, packet error rate has been effectively reduced by use of dual-hop relaying communication systems with different techniques [2].

Nodes placement on the body allow us to define three main types of body centric wireless communications: in-body, on-body and body-to-body networks shown in [2].

1. **In-body network**: Implantable antennas are used in this type of BANs. Antennas with the electronic circuitry is implanted inside the human body by means of surgical operation. Implants under the skin or deep implants are included in this type of BANs such as implants inside the bones. Huge number of people around the world depend on these types of implantable medical devices to improve their health conditions and to gather information to improve their health. These wireless medical implants have a variety of applications such as pacemaker, insulin injector devices and many others. With the advancement of

technology in near future their use is expected to grow rapidly. Ingestible medical devices are also considered to be related to this type of BANs. Antennas are integrated on the devices and in the form of small sizes capsule are ingested by the patient. These capsules wirelessly transmit the video and other related information of patient's body to diagnose and study certain intestine track disease.

2. **On-body network**: The antennas are basically placed on the body and afterwards are integrated on devices for communication with external network. For example, in healthcare sector devices like temperature sensors, pulse monitoring sensors and many other medical devices are integrated with antennas that are on body of the patient and thus making a BAN and communicating the information from the patient body to some external network.

3. **Body-to-body network:** Network consists of one antenna placed on the body and one positioned off body. This node maybe worn by other human body. BBN communication devices communicate on relatively longer distances and should have a long-lasting power source.

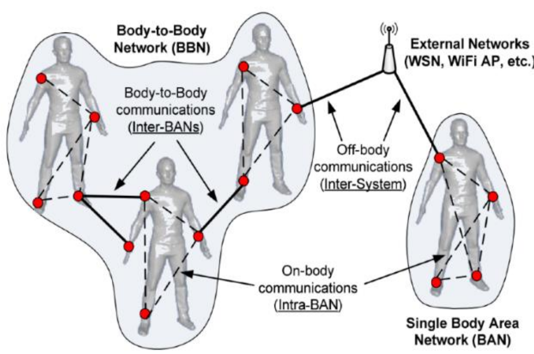

Figure 1 *- Communication links for body-centric wireless communication [3].*

As already pointed out in the above section, The concept of body area networks BANs supports body centric communication. Protocols design optimization and system architecture which includes a look on the PHY, MAC layer is detailed in sec. 1.4. and 2. summarizes some of the standardized wireless technologies for BANs.

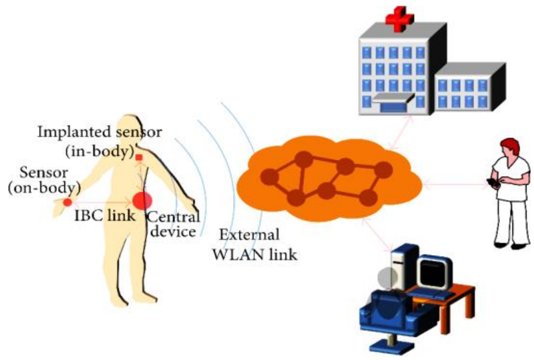

__Figure 2__ - Body area network scheme with wireless links. Sensors on the body or implanted inside the body gather the data and then send to central excess point from where its send to medical centre where they are further analysed and saved [4].

1.2. Applications of Body Area Networks

Advancement in electronics, wireless communication systems and power efficient sensors have all made a significant contribution to the increasing application of BANs [3] [4], supplement BANs, which are more concentrating on interconnecting one person's wearable devices. Fig. 1.1, shows several connections between different bodies using different wireless technologies. A Human body is important features that distinguishes BANs from traditional WSNs. On-body and body-to-body channels exhibit unique propagation phenomena that is different from conventional channel models which are dependent on the distance and therefore must be carefully characterized [5]. PHY and upper layer communication protocols (MAC) are also affected, therefore Common WSN systems cannot be optimized for body-centric communications [6]. Furthermore, because human bodies are carrying nodes, they have inherent interaction and movement, which presents endless possibilities.

Some techniques should be devised to overcome the effect of interference to work in heavily populated areas [7], or utilising all these users to form a carefully orchestrated "network of people" [8].

Because of the ability to apply multiple wireless nodes on the human body suggests that BANs could be used in a range of applications, ranging from entertainment to military and location tracking, or healthcare sector. Following are some of the applications that implies use of BANs [9].

1. **Industrial Application**: BANs can improve worker safety in the workplace, for instance, we can monitor the workers movements and their surroundings to avoid exposure to harmful gases or level of radiations. BANs can also be used for observing the vibration levels that works are exposed to while operating heavy machinery [10].

2. **Disaster Management or Rescue Work:** Firefighters, police officers, or rescue management departments can take advantage by use of BANs in the field of public safety for example, police and firefighter suits can use gps or multimedia communication devices and sensors e.g., Outdoor temperature, co2 level sensors can be installed for the improvement of working environment and for increasing the safety of workers, and to notify them of any situation that could be life threatening. Remote viewing or acoustic detection techniques can also help greatly in guiding rescue teams in disaster rescue operations [11].

3. **Healthcare Industry:** At first brief look, healthcare appears to be among the most promising application for BANs. The continuous monitoring of vital parameters is feasible thanks to several implantable sensors inside or on the body. Situations demanding immediate action, such as a cardiac arrest, can be diagnosed early and even predicted. Hearing aids, cochlear implants, and artificial retina are all instances of BANs that can help improve lives of people with hearing disability or visual impairment [12]. Drugs delivery, Electrocardiogram (ECG), post-operative monitoring of important body organs, Electromyogram (EMG) and body parameters like blood sugar level, blood oxygen level, toxicants, body temperature and blood pressure measurement are just a few examples of medical applications that can benefit from BAN use [13].

4. **Combat And Civil Defence:** The possibilities for using BANs in the combat and army are numerous. Observing health and location is part of the military use for BANs. A combat uniform with a body area network may be transformed into a suitable computerized system that connects devices such health monitors, gps, data sharing devices between troopers conducting security operations. [14] gives an insight on different techniques for communication between troopers and data encryption to prevent the enemy from acquiring important security related data [15].

5. **Entertainment And Sports:** A concurrent recording of key parameters such as heart rate, blood oximetry, blood pressure and body position can help athletes improve their fitness and performance. Users can gather information about their sport activity in this way, which they can use for the prevention of fatal injuries and anticipate new techniques to enhance their performance [16]. In the field of entertainment, BANs can enhance the level of realism of the user. Motion capturing methodologies use a set of gyroscopes and accelerometers that are worn by the user and are worn in a way that they are remotely linked to a central node in order to monitor the location of different body parts. The ability to use the user's body as a controller in gaming is made possible by real-time motion information. [17]

6. **Daily Life Applications**: Emotion detection, internet of things devices, object and location tracking, smart keys, identity management are just some of the applications that can be envisioned in this last domain. BANs, for example, people’s vitals can be monitored to get data for the establishment of systems that can change the surroundings of users like soundtrack, illuminance, and ambient temperature based on their emotional situation [18] [19].

2. System Prerequisites for BANs

Because of the vast range of potential applications outlined in chapter 2, there are an equal range of different system requirements that must be addressed. Following is a list of the most important ones, organized according to the categorization. [20]

Many of these features put constraints on design of BAN which leads to the development of specialized protocols and system implementations. Given the compact footprint of devices (and batteries) possibility of nodes that can be worn on body, BANs must function effectively inside a congested area in which other systems may be utilizing the same frequency band, power consumption and co-occurrence constraints are also considered critical elements [21].

Following are some of the detailed requirements for a BAN system:

1. **Device Size:** limitations on the device size might be substantial; main issue is putting antenna and battery in a small sized housing while maintaining optimal radiation pattern and longevity. This can be useful in case of devices that are implantable but, for nodes that are worn on the body, agility and flexibility may be even more important factors in terms of user comfort, particularly in sports, and military combat applications. [22] [23]is a good place to begin for latest concepts in stretchable electronics, while [24] [25]is a good place to start for flexible antennas and RF circuit design

2. **Radio Signal Processing:** BAN devices cannot be power hungry and one of the power-hungry components is radio component [26]. Therefore, techniques like compressed sensing might be helpful in power saving in signal processing and can assist the developer in keeping the entire system energy usage under control. This technique also enables the sampling of weak analogue signal at a sub-Nyquist rate, conserving power and retaining information in the signal [27] BAN applications have been frequently using CS; [28] provides a brief view with all the applications.

3. **Battery Consumption**: The amount of power consumed is highly dependent on the application's nature. BAN devices, on the other hand, are often powered by a battery and

the battery is expected to last for many years especially for implants e.g., pacemaker [29]. Radio transmitter and receiver must be developed with ultra-low power usage in mind, as well as energy-efficient MAC protocols. The latter is frequently accomplished by reducing device duty-cycle at the price of end-to-end latency. This allows devices to be in sleep mode (transceiver and CPU turned off) for most of the time, which is a good option for apps that only need to send data occasionally. However, there must be a reasonable trade-off between transmission latency and power usage. Scavenging energy from body heat or human actions can also be an option to increase battery life. [30] [31].

4. **Antenna And Channel Modelling:** Antenna design is a significant problem, and nanotechnology research should contribute to relatively efficient solutions, constantly considering the right trade-off between antenna size and efficiency [32] [33]. Furthermore, the human body's presence cannot be overlooked since it has an impact on antenna radiation and polarization properties depending on the unique on-body position [34]. As a result, in order to create antennas with the requisite radiation properties, proper radio channel characterization is essential.

5. **Topology and Coverage area**: In most of applications, the range of communication should be no more than a few meters, hence a basic star topology may be used. The human body, on the other hand, might be a barrier to radio transmission, particularly for implanted nodes. In this instance, a multi-hop connection must be formed, and a relaying strategy must be considered in order to take use of node geographical diversity [35] [36]. The number of nodes that make up the BAN can range from two to hundreds and can change over time. As a result, to allow nodes to join and depart the network as needed by the application, trustworthy association and disassociation methods should be explore [21].

6. **Data Security:** Data security is critical, particularly in military applications and in healthcare applications, and should be handled in terms of privacy, authorization, and integrity. Each standard, as is shown in Sec. 1.5, includes certain strategies for dealing with security challenges. Due to the low processing capacity, memory, and energy limits of BAN nodes, traditional data encryption techniques or authentication processes are not ideal for

BANs. As a result, innovative resource-efficient and lightweight approaches are being developed [37]. Biometric identification-based systems are a viable approach in this area [38] [39].

7. **Quality of Service (Qos) And Bit Rate Requirements:** Data rate requirements vary widely according to the type of application and the kind of information being delivered. It ranges from below one kbps to ten megabits per second for example in case of video streaming. [40] proposes several prospective applications with specific bit rate requirements. Medical and military applications demand a high degree of QoS, with suitable collision-avoidance and error detection and mitigation strategies applied at PHY layer and MAC layer to lower Bit Error Rate (BER). End-to-end latency, delay variation, and the capacity to respond quickly and reliably to emergency events are all significant QoS indicators. Table no.1 a few BAN applications with their bit rate requirements and expected quality of service in various scenarios. moreover, the capacity to manage traffic with varying priority levels is critical for these types of networks. [20].

***Table 1** : Some BAN applications with bitrate and quality-of-service requirements. [41]*

Application	**Delay**	**BER**	**Bitrate**
Audio streaming	< 45 ms	$< 10^{-5}$	1 Mbps
Video streaming	< 125 ms	$< 10^{-3}$	< 10 Mbps
Capsule endoscope	< 250 ms	$< 10^{-10}$	1 Mbps
Drug delivery	< 250 ms	$< 10^{-10}$	< 16 kbps
ECG	< 250 ms	$< 10^{-10}$	192 kbps
EMG	< 200 ms	$< 10^{-10}$	1.536 Mbps
Blood sugar monitor	< 250 ms	$< 10^{-10}$	< 1 kbps

2.1. BANs System Design

The criteria listed above illustrate the variety and complexity of factors to consider while dealing with BAN architecture. Some factors have a greater influence on the PHY layer, while others have a greater impact on the protocol architecture of the higher levels. In any case, while dealing with these sorts of networks, the most difficult tasks for any system designer are flexibility and adaptability. Channel modelling is crucial for the designing and analysis of the suitable signalling technique to utilize in the PHY layer. An optimal channel characterization is required to permit a more suitable antenna design as well as the analysis of different implementations done on MAC and PHY layers.

A lot of study has been conducted for the characterization of the transmission channel, as detailed in section 3 and sec. 2, concentrating on several radio frequency bands both at ultra-wideband (UWB) and narrowband (NB). Other wireless communication technologies, such as biochemical communication channels or Human Body Communication (HBC), that take advantage of human body and use it as a medium of communication operating in the frequency range of 5 to 50 MHz [46] [47], have recently been investigated as feasible options to more conventional radio bands. The channel characterization results reveal a great deal of variation, even when they're all around same specific frequency. This highlights the significance of the surroundings, user's mobility, and the individual node position in defining channel characteristics. Furthermore, the workplace and the location of user also effect on the choice of antenna architecture, both of which effect the radiation pattern [42]. The optimal antenna design should always be properly considered in relation to the desired application, taking device size and radiated power limitations into account.

Support for the layers above from the PHY layer's perspective, the BAN protocol design results in a compromise between power consumption, bit rate and communication distance. In dynamic and interfered environments, Modulation techniques must ensure that the necessary data transmission rate are achieved while retaining communication reliability. [21].

Usually, MAC protocols are defined in two types of configurations scheduling-based MAC and Contention-based MAC. For first instance, nodes compete for data transmission channels. When the channel is congested, the node postpones sending data until the channel is accessible. These protocols are robust, responsive to frequent changes in traffic, and don't impose strict time synchronization requirements but they add a lot of protocol overhead. In scheduling-based approaches, the channel is divided into variable or fixed size time slots. Nodes are given these slots, and every node broadcasts in its allotted time slot. Although these types of protocols are efficient in terms of power consumption, idle listening and many other aspects, the necessity for regular synchronization is their most significant limitation. [43]. other aspects to be considered includes information filtering, alarm management, and self-organizing and easy network design [18].

Finally, some insights on the attributes of the NET layer are mentioned. Its major functions are route identification, creation, and management [42]. It ensures that packets are sent successfully from a source to a destination node across many relaying nodes. The development of effective routing algorithms for BANs is a complex undertaking due to the unique features of the wireless environment on the human body. The approaches utilized in normal WSNs are inadequate owing to strict limitations on energy utilization by node, transmission power and occasional node topology modification because of body mobility [43]. The right network topology is also a vital factor to investigate for this purpose, as it has an impact on overall protocol design and system performance. Given the fact that the star topology has long been promoted for a variety of BAN systems, recent research has focused on analysing the benefits of including various types of relaying and node interaction. [35] [36].

Considering this general perspective of BAN system architecture, the next chapter will go over the decisions made for different levels of the protocol stack by various standardisation bodies to fulfil technical specifications and system features.

3. Standardization and Wireless technologies

The potential wireless technologies for BANs are described in this section. Earlier standards especially Bluetooth, IEEE 802.15.4 and IEEE 802.15.6 [44], primarily designed to function in relatively traditional wireless sensor networks (WSN) applications and hence fail to fulfil all the technical criteria mentioned in Sec 1.2.

Recognizing the lack of an appropriate standard designed particularly for wireless communications around human body, a task group named as IEEE 802.15.6 was established. The main goal of this group was the development of MAC and PHY layers. Its goal is to offer the combination of robustness, low power consumption, high data rate, and non-interference necessary for BAN applications in general [41]. An essential and the first process in the widespread adoption of any communication technology is dependent on the standardization, and it serves as a reference for both suppliers and consumers, as well as fostering interoperability with other operational standards.

Over the last decade, the Zigbee WSN and the IEEE 802.15.4 standard have left a legacy. Such devices and protocol designs remained important in health and wellbeing applications such as monitoring in hospital wards and intensive care units. Other variations of this standard focused on the medical body area network (MBAN) in the 2.36 GHz to 2.4 GHz frequency range prior to the saturated narrow band spectrum. But this is confined to healthcare applications, where the wireless channel's dynamic mobility and space–time changes have less of an impact and hence such characteristics are not desired.

3.1. IEEE 802.15.4 Standard

IEEE 802.15.4 standard was designed to meet the latency and throughput requirements of applications in local area networks. Low complexity, inexpensive, less energy consumption, and low data rate transmissions are the important attributes, which may be provided by either stationary or mobile low-cost devices

The following are some of the features incorporated in this standard:

- 40 kbps, 20 kbps, and 250 kbps data speeds are present.

- Two addressing modes: 64-bit IEEE and 16-bit short.
- Analogue sticks as well as other low-latency devices are supported.
- The ability to use the CSMA-CA channel.
- The coordinator automatically establishes a network using a fully handshake protocol for transfer reliability.
- To achieve minimal power usage, power management is used.

The standard provides a set of 27 half-duplex channels, which are divided into three unlicensed bands given as follows:

- The frequency spectrum of 8680 to 8686 MHz, only used in Europe which consists only one channel. A transfer rate of 20 kbit/s is achievable.
- 902 to 928 MHz, used widely in north America. Ten channels with a transfer rate up to 40 kbit/s are available.
- The frequency range of 2400 to 2483.5 MHz used worldwide. This frequency band is divided into sixteen channels with transfer rate up to 250kbit/s.

This standard specifies two types of PHY layers based on direct-sequence spectrum technique according to the modulation scheme used (that can be either binary or QPSK). One is working in 868Mhz and 915Mhz band. Other is working in 2450Mhz band

It's worth mentioning that this standard only enables for relatively low bit rates, which might be a problem in some BAN cases when higher data rates are necessary, as in the transmission of music or video.

The standard describes a MAC layer protocol based only on a CSMA/CA technique. Essential responsibilities of MAC layer include Connection formation, data encryption, beacon generation and scheduling, creation of acknowledgement (ACK), and software and operating system support for star and peer-to-peer network topologies. [9].

Two types of modes are present in which a network operator can operate. beaconing and non-beaconing mode, corresponding to two alternative channel access techniques. In beaconing mode, coordinator establishes an SF by issuing a beacon packet.

In order to get access to the channel, nodes use an unslotted CSMA/CA protocol, and they send their data packets using a non-beaconing mode, and no SF structure is established. The standard also specifies an encryption technique for encoding data for transmission. However, there is no indication of how the keys should be handled or what type of authentication procedures should be used, and this operation is handled by the upper layers. The approach employed is known as Advanced Encryption Standard (AES) which has a key of length equal to 128-bit and is used for encryption and authentication of the sent data. This is also known as data validity, and it is executed by attaching a code to the message and then again verifying it [41].

3.2. IEEE 802.15.6 Standard

This standard offers degree of freedom in the PHY layer selection. A single PHY solution does not appear to be a viable choice for meeting the large range of system needs arising from diverse applications, hence the idea describes three alternative solutions.

The PHY and MAC layers are defined in the standard. Three physical layers are supported by this standard namely Narrowband ultrawide band and human body communication. To build a stable link between WBAN transmitter and reception devices, the PHY layer handles modulation and error correction functions. PHY converts data to be transported into an air interface-compatible format, considering varying frequency requirements. The MAC layer oversees channel access for a variety of WBAN devices.

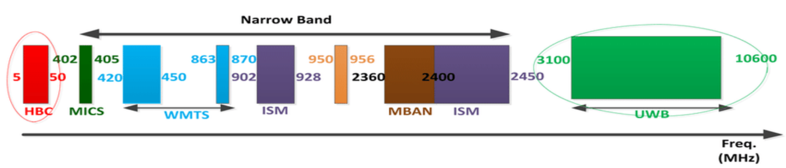

Figure 3 - Frequency bands distribution according to IEEE 802.15.6 standard [47]

This standard is frequently utilized in eHealth and remote healthcare applications. The standard offers three degrees of security to give a higher level of protection over the air interface.

Table 2 : functionalities that 802.15.6 standard supports [45].

Specifications	IEEE 802.15.6 support
Power Consumption	About 1 to 10 mWatt
Data rate	up to about 2 Mbps
Frequency bands	2.4GHz, 800MHz,900MHz,400MHz
Range	less than about 0.01 to 2 meters
PHY Layers	NB, UWB, HBC

Following are the frequency bands proposed in IEEE802.15.6 standard the frequency bands as well as some information about them. It can also be illustrated by the help of figure that is given as figure.3

- 405 to 405Mhz: it's a narrowband and is widely used but the available bandwidth is limited.
- 420 to 450MHz: it's a narrowband band used only in Japan and is WMTS band.
- 863 to 870 MHz: NB WMTS band is widely used in Europe.
- 902 to 928Mhz: its widely available to be used in north America, New Zealand and Australia. Its ISM band.
- 950 to 956Mhz: NB its available to be used in Japan.
- 2360 to 2400MHz: it's a new band adopted to be used for Ban applications. It's narrowband.
- 2400 to 2450MHz: it's a narrowband available worldwide.
- 3100 to 10600MHz: Ultrawide band UWB.

4. Channel Models for body Centric Communication

4.1. Overview

The design of medium access layer and physical layer being adopted in the BANs presents several issues because of highly complicated electromagnetic behaviour and rapidly changing channel conditions. This process is made more complicated by the limitations imposed on the dimensions and energy utilization of BAN nodes. In the PHY layer, nodes use for BANs must be small and light, resilient, and invisible to the user, with antennas arranged conformally close to user. Protocols for MAC layer must be resistant to interruptions, interruptions caused by the human body casting shadows on the link. The configuration of the channel model for scenarios involving a layer of skin and an implant is distinctive. The implant device's channel model is substantially different.

A few scenarios in which IEEE802.15.6 devices will be used can be recognized.

Table **3** lists these instances, along with their descriptions and frequency bands. The scenarios are depending on where the connecting nodes are located. The situations are divided into classes that can all be represented using the same Channel Models (CM) [46].

Table 3 *: Some scenarios with description frequency band and channel model [46]*

Scenario	**Channel Model**	**Brief Description**	**Frequency Range**
S1	CM1	From one body implanted device other to implanted device	402 to 405 MHz
S2	CM2	From body Implanted device to device on the Surface of body	402 to 405 MHz
S3	CM2	From body Implanted device to non-implant device	402 to 405 MHz
S4	CM3	From device on Surface of body to another Body Surface device for line-of-sight propagation	900 MHz, 3.1 to 10.6 GHZ
S5	CM3	From device on Surface of body to another Body Surface device for non-line-of sight propagation	400 MHz, 600 MHz, 900 MHz 2.4 GHz, 3.1 to 10.6 GHZ
S6	CM4	From Body Surface to some device off the body for line-of-sight propagation	900 MHz 2.4 GHz, 3.1 to 10.6 GHZ
S7	CM4	From Body Surface to some device off the body non-line-of sight propagation	900 MHz 2.4GHz, 3.1-10.6 GHZ

The location of the nodes on the body of user result in the formulation of these scenarios. This leads to categorization of BAN nodes which are as follows:

- Implant node: In this type a node is implanted within the human body. This might be anywhere from just beneath the epidermis to deep into the human tissue.
- Body Surface node: The node that is positioned on the external surface of human skin. or within 2 millimetres of it.
- External node: A node that does not come into touch with human skin (a few millimetres to 5 meters distant from the body).

Figure 4 depicts the scenarios along with the relative channel model.

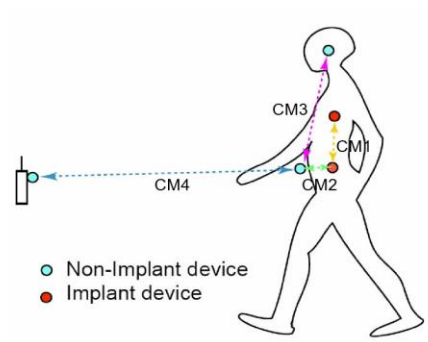

Figure 4 *- IEEE 802.15.6 channel models [49]*

4.2. Ultrawideband Channel Models

The signal bandwidth above 500mhz is termed as ultrawideband technology. The utilization of less power spectrum is possible because of large bandwidth available, which have variety of benefits including low interference, reduced fading sensitivity, localization capability and lower system complexity. As a result, UWB has swiftly become a crucial technology for bans, prompting several channel characterizations and modelling studies.

UWB channel measurements, like narrowband measurements, typically use a vector network analyser with a frequency range of 3–10 GHz, even though other researchers limit the bandwidth to 3–6 GHz or sometimes 6–10 GHz. Instances include both LOS and NLOS propagation in anechoic and interior situations. Tx and Rx node sites are also restricted in certain studies to specific areas of the body, like the chest and waistline. The channel impulse response (CIR) for UWB and path loss are measured parameters which are approximated using stochastic models. Power delay profile characteristics or discrete tap delay lines models are determined by the initial tap's received power or the corresponding path loss, fading patterns, power depreciation of each tap, and sometimes inter-tap coupling.

4.2.1. Empirical Channel Models

Empirical channel models largely rely on UWB CIR stochastic modelling, with data used to build tapped delay line TDL which is discrete or continuous power delay profile model. The CIR is specified by a model namely as tap delay line model as a collection of L complex pathways, each with its own phase ϕ_l,latency τ_l and amplitude a_l:

$$h(t,\tau) = \sum_{l=1}^{L} a_l(t)\exp(j\phi_l)\delta(\tau - \tau_l)$$

The above-mentioned equation can be represented in a general form by converting pathways in cluster form resulting in following expression:

$$h(t,\tau) = \sum_{m=1}^{M} \sum_{l=1}^{L_m} a_{ml}(t)\exp(j\phi_{ml})\delta(\tau - \tau_{ml})$$

here, L_m represents the path number in the cluster and M represents no. of clusters.

The measuring of the amplitude is the initial aspect of any tap delay line model. It's commonly thought of as a fading variable, a delay furcation with a decreasing mean. In most research, one cluster is taken under consideration, and the amplitude degradation is modelled using only one slope:

$$\begin{aligned} a_l|_{dB} &= 10 \cdot \log_{10}\left[\exp\left(-\frac{\tau_l}{\Gamma}\right)\right] - P_{dB} + S \\ &= -4.34\frac{\tau_l}{\Gamma} - P_{dB} + S \end{aligned}$$

Here P_{db} represent the the path loss model, Γ represent multipath profile degradation rate, whereas S represent a stochastic factor that represents the extra fading behaviour of each tap, which is commonly regarded lognormal.

For anechoic settings, [47] established a two-slope model that considers propagation linkages throughout the human skeleton. Each cluster intuitively symbolizes 1 propagation path from around body, and cut-off delay indicates the relative delay between two clusters, that is, waves coming from the opposite direction as the first wave did in comparison to the other waves. With an increase in distance between the transmitter and receiver (Tx and Rx), the initial slope gets significantly steeper, with an average value of 1/ 240 s. The second slope, on the other hand, is a constant, 2 = 1 ns still matching to on-body transmission. The variable S represents each tap's fading. Some studies make a distinction between fading on a wide scale and fading on a small scale, claiming that both are lognormal. Some models, on the other hand, without taking in account the scale of fading considered it as one lognormal. Small-scale fading is most often maintained because of the ultrawide bandwidth and seldom Rayleigh propagated. Unfortunately, this suggests that it is hard to distinguish from large-scale fading. As a result, several studies assume S to be Gaussian with a standard deviation, characterized by the combined effect of small-scale and large-scale fading.

The model presented in equation 2 only contains a single cluster. [48] employ a model with two clusters to depict indoors conditions, with the very first cluster representing on-body transmission and the other cluster is generated because of environmental influences or floor reflection. Each cluster in this type of scenario is defined by an expression like equation 2, with a different rate of decay for each cluster. The torso propagation model proposed by [48] provides value ranges for Γ 1 from 300 s in case of front with line of sight and 460 s for back with Non line of sight and equivalent range for Γ 2. [48] also observed that taps with varying delays are related with a correlation coefficient of 0.8 within the first cluster.

4.2.2. Path Loss Models

The wide range of BAN links makes implementing a unique distance-dependent model to every case difficult. As a result, many models merely include a computational loss (or power received) for every form of connection, or mathematically describe all numerical values using a probabilistic model or PDF with a standard deviation and average value.

Alternatively, under specific cases, some path loss models that were dependent on the distance were developed. [48] specifically advocated using a power decay rule for links around the torso, so that the path loss translates as:

$$P_{dB}(d) = P_0 + 10n\log_{10}\left(\frac{d}{d_0}\right) + N$$

N is a variable with a normal distribution with a zero mean and standard deviation σ_N, and the path loss exponent is given as $n = 7.2$. [49] calculated n = 3.3 in anechoic settings and 2.7 indoors for linkages alongside the body. In contrast, [47] used an exponential model to fit the distance dependency around the torso.

$$P_{dB}(d) = P_0 + m(d - d_0) + N$$

UWB channel types are proposed for use in a variety of applications, including on-body communication, under the IEEE 802.15.4a standard, all of which use equation 4 as their path loss model. Electromagnetic simulations were used to derive this model with frequencies ranging from 2 to 6 GHz. in its first edition, it was also restricted to cases in which antennas were placed primarily on the trunk of human body in an environment that is free of echoes with ground reflections only, possibly representing an outdoor environment. Electromagnetic computations for frequencies in the Gigahertz show the existence of creeping waves around the trunk and apparently non-penetration of waves in the body. As a result, rather than a straight line through the body, the distance among the transmitting antenna and receiving antenna was determined by the circumference of the body.

Further observations in the frequency band 3.1–10.6 GHz were made in the framework of IEEE 802.15.6 for UWB on-body channel modelling to further optimize the parameters of equation 4, the results of which are shown in Table 4.

Table 4 : *CM3A model [49]*

Parameter	Hospital Room	Anechoic Chamber
d_0 (mm)	1	1
n	1.92	3.41
P_0 (dB)	3.38	-31.40
σ_N (dB)	4.40	4.85

4.3. Narrowband Channel Models

There are many parameters that affect the wireless channel properties for BAN application domains, but statistical processing is frequently more convenient because it assigns a probabilistic distribution to a performance variable like the phase or signal received given a certain scenario. To further facilitate the research, BAN channels are frequently analysed in different contexts, with individual user activities considered independently for example, if you're strolling in a lobby, going through an outdoor office space, or sprinting outside. If appropriate, these data may be provided independently or combined to construct more detailed models. Several bands, including as the MICS and ISM bands, are relevant for BAN applications. Different narrowband PHYs are suggested in the IEEE 802.15.6 standard. On the other hand, most of the research on channel modelling that has been documented in published works has focused on the 868 MHz band as well as the worldwide 2.4 GHz frequency. Because of this, the following part will concentrate on channel modelling in these ranges.

4.3.1. Path Loss Models

Because of the anatomy of human body and the vast variety of potential source and the destination trajectories, it is challenging to transmit wireless signals. When applying a generic path loss model that is related to distance to data that was gathered by on-body channels, it can be difficult to provide accurate results. Consider an on-body link that extends from the front upper right arm to the front right waistline (in line of sight). Now consider a connection of equal length that extends from the right front waistline to the lumbar side waist along the waistline. Despite its same length, the path is non-line of sight (NLOS), prone to significantly different propagating methods, and so likely to experience significantly more attenuation. Path loss approaches have been considered inappropriate for BAN communications due to their inability to take only one approach. Despite this, a huge proportion of research has been done on path loss models for BAN systems for instances and networks that have been defined in a very precise manner. [50] cites the design of an analytical model which is also a path loss model which takes inspiration from the Friis equation over free space at bandwidth of 2.4 GHz for on-body communication with transmitter and receiver spacing of 40 cm. The authors examined the relationship of the height of antenna on skin and channel model specifications using a homogeneous, lossy medium that mimicked human tissue.

The conventional method of modelling path loss, widely recognized as the component of the distance P(d), has been utilized in the IEEE 802.15.6 channel estimation, even though it is debatable owing to the issue stated above, the links present in the on-body scenario having equal distances but exabit different attenuation and different propagation mechanism. This also shows path loss is mostly different for path with same length., however IEEE 802.15.6 paper proposed a power law model which is given below:

$$P_{dB}\left(d_{[mm]}\right) = a \cdot \log\left(d_{[mm]}\right) + b + N$$

Here channel model parameters are given by a and b, N is a normally distributed variable that is cantered and has a standard deviation of σ_N, and d is the transmitter-receiver separation in this case, stated in millimeters. It is important to note that the model parameters shown in Table 5 were obtained from measurements carried out in the frequency range of 2.4 to 2.5 GHz.

Table 5 *: CM3A Model Parameters [49]*

Parameter	Hospital Room	Anechoic Chamber
a	6.60	29.3
b	36.1	−16.8
σ_N	3.80	6.89

[46] proposed a model that is "hybrid" in nature which combines a local propagation model with the environment having an influence that results in an exponential factor first for "short distances" and then a "saturation" for extended distances. It has been proposed for narrowband channels at 915 MHz as well as 2.4 GHz. The corresponding formula is as follows:

$$P_{dB}\left(d_{[cm]}\right) = -10 \cdot \log_{10}\left(P_0 e^{-m_0 d_{(m)}} + P_1\right) + \sigma_p n_p$$

The data taken in the 2.45 GHz frequency region serve as the foundation for this model. Around the outside of the body, the path loss drops off far more quickly. As a result of the presence of Multipath components originating from the indoor atmosphere, it becomes more uniform across great distances. Table 6 presents the values of its state variables.

***Table 6** : CM3B Model Parameters [49]*

Parameter	Value
P_0[dB]	−25.8
m_0[dB/cm]	2.0
P_1[dB]	−71.3
σ_p[dB]	3.6

[51] Instead of using the traditional approach, used a new way to mimic the path loss surrounding the entire body based on the angle seen between transmitter and the receiver antennas The finite difference time domain technique in this study, FDTD was utilized to investigate wave propagation throughout the body at eight varying heights using simulation models at 2.4 GHz, 900 MHz and 400 MHz. At 15 radial positions that followed the curvature of the body, the field that was radiating from a dipole antenna that had been positioned in front of the body was evaluated for every segment. When observed from a specific viewpoint, the propagation surrounding the body transforms to interference domain. The creeping wave in clockwise and creeping wave in the anticlockwise direction starts to interact. There is less degeneration in the interference domain, but the field fluctuation is much greater. The creeping wave's amplitude and wavelength are inversely proportional to the zone's width. [51] proposed path loss model based on a double slope:

$$\begin{aligned} P_{dB}(\theta) &= P_{dB}(\theta_0) - \gamma_1(\theta - \theta_0) && \text{for } \theta_0 < \theta \le \theta_{bp} \\ P_{dB}(\theta) &= P_{dB}(\theta_{bp}) - \gamma_2(\theta - \theta_{bp}) && \text{for } \theta_{bp} < \theta \le \pi \end{aligned}$$

where γ_i is the degradation coefficient and θ_{bp} is the break point angle given in the equation above.

4.3.2. Fading

Propagation pathways in body area network communications might face fading for a variety of causes, involving the absorbing of energy, reflecting of sight, diffracting of beam, casting of shadows by the body, and positioning of the body. Another explanation for fading might be multipath caused by the surroundings around the body. Fading is categorized into two main types namely small scale fading and large scale fading.

Small scale fading can be defined as rapid variations in the amplitude and phase of the received signal within a particular region. These variations are caused by small variations in the location of the on-body device or body postures that occur over a brief span of time. Small scale fading can be caused by a variety of factors. Two forms of fading that occur on a small scale are known as flat fading and frequency selective fading.

Large scale fading refers to fading that is generated by motion across a large region, this is related to the distance seen between the external node and the antenna positioning on the body.

In the interference domain, the field degrades less. As defined above fading in on-body communications channels is mainly caused by combination of small-scale fading and body shadowing. Multipath created by the immediate surroundings becomes a key component in BAN channels when working in reverberant situations and cannot be disregarded [52]. When human flesh and moving limbs hinder the signal route between the sending and receiving nodes in BAN channels, a phenomenon known as body shadowing occurs. The variable size and human skin tissue composition that obscures the on-body link will affect its amplitude [53].

[54] tested wireless connection between two body-mounted microstrip patch antennas. The body, the head, and the clothing each reduced the signal by a corresponding 19.3, 13.0, and 1.7 db. Shadowing caused by the human body presents a significant obstacle to the successful implementation of millimetre-wave on-body communications operating at 60 GHz, where the shadowing effect of the body will impact the inability to communicate without line-of-sight obstructions NLOS. [55].

5. Body to body and off body channel models

Despite the significant amount of work that has been done into researching the data transmission patterns and On-body communication channel parameters, as well as body-to-body (or interbody) communication channel parameters, have received a significant amount of attention, whereas off-body communication channel parameters have not. This section offers a brief summary of the findings of the study that is currently being conducted on channel modeling for developing new capabilities of body-centric communication.

5.1. Off-body channels

In [56], one of the very first efforts to offer a comprehensive description of the properties of the off-body channel were made. The authors studied two different interior settings and compared the data that was observed to the simulations that were conducted on a narrowband radio channel model operating at 5.2 GHz (a hallway and a workplace). Simulated results were generated employing a method based on 3-D images for the prediction of propagation, whereas the trials employed a stationary transmitter with a receiver at thigh of a user who is moving closer to or further from the transmitter. There were various issues in NLOS situations when the simulation tool was used that should have been addressed. It was found that Rayleigh and lognormal distributions combined to create the optimal match for corridor environments, whereas lognormal distributions generated the best match for office environments, according to a quantitative analysis of small-scale fading [57].

[52] looked at off-body communications on the 868 MHz frequency. Several receiving antennas were attached to the user's body, a variety of environments (such as echo free room, an open workplace, and a corridor), line-of-sight and non-line-of-sight circumstances, and walking movement were all taken into consideration. Upon evaluation of the data from the channel it indicates that human body movement and the position of the antenna both have a substantial influence on the indoor propagation characteristics of wearable devices. In addition, it was discovered that the Nakagami-m distribution provided the greatest fit for the majority of the off-body propagation channels that were examined in anechoic as well as indoor multipath environments. Because, unlike other distributions like Rice as well as Rayleigh, it does not imply

scattered components of equal amplitude, this distribution proved to be adequate for the scenarios that were considered. [57].

A lot of researchers have focused on channel characterization at UWB frequencies because of the potentially significant benefits that could improve to the performance of the system. These benefits include a reduction in multipath fading, the capacity to attain higher data transmission rates, and lower power utilization. The authors of [58] and [59] proposed modeling channel for off-body communication by combining the conventional formula for distance-dependent path loss with an equation of multi-slope propagation loss that was derived via research on the methodology of propagation schemes surrounding the body also termed as creeping waves. This was done to show that the off-body communication channel was be located outside of the body [57].

[60] revealed the findings of a measurement experiment that was carried out in an actual hospital setting for both static and movable UWB off-body channels. The investigation was carried out for both types of off-body transmissions. The observations of LOS and NLOS that were taken in movable situations both displayed lognormally distributed fading, with the former having a much greater standard deviation than the latter. Signal strength assessments taken in stationary conditions were found to be impacted by the direction the user was facing [57]. The authors of [61] [57] analyzed the use of the UWB channel for off-body as well as on-body communications. A two-state Weibull renewal process with a minimal model has been offered to characterize the channel behavior. This process was developed as a result of research into various movements that occur in hospital settings.

5.2. Body to Body channels

Several research groups have conducted measurement operations to characterize the interbody channel. In the cited article [62] a methodological study of body-to-body channels dynamics is presented that were operating at 2.45 GHz. They investigated using a scenario that mimicked the domestic sweep and rescue operations conducted by firefighters and rescue workers. In this scenario, four group members moved throughout a building. One fireman was equipped with a transmitter, while the remaining three served as receivers. [57]. The authors indicated that indeed k- distribution seemed to produce a satisfactory approximation to the estimation of small fading for all the connections that were studied, in contrast to fading models including the Nakagami-m model, the lognormal model, the Rice model, and the Weibull model. This was demonstrated by comparing the ***k-μ*** distribution to these other fading models. The researchers came up with the concept of utilizing spatial variety as a means of improving the output of the channel for body-to-body communications after observing that there had been minimal similarity as a function of displacement relative to other and equivalent average signal amplitude in such trials.

[63] describes an analytically different analysis to explain the body-to-body channel characteristics. An extended measurement campaign that included two people was used by the authors to analyze the properties of the waves that travel through the frequency bands that are centered at 2.45 GHz and 5.8 GHz in an office environment (first with a transmitter and second person with receiver). The participants were separated by a range of distances and asked to perform a variety of arbitrary activities while assuming a range of arbitrary body positions. The mean and variance values of channel path gain variations were determined to comply with the power law with regard to the distance that separates two BANs. This was discovered after it was found that channel path gain variations follow a gamma distribution. Although, strictly speaking, it was shown that the rate of reduction was nearly independent of the frequency that was being considered, while still being closely bound to the device's position on the body and the body's orientation.

[64] conducted research on Ultra-Wide Band (UWB) Interbody Communications. The path loss, which was calculated using the traditional formula that is dependent on the distance, was shown to have a significant correlation with the orientation of device placed on the body and the postures of the bodies in relative to one another, according to the findings of data collected in an anechoic chamber environment for two subjects standing at different distances and with different body orientations. [57]. The authors of [65] provided a solution to the interference issue by utilizing a stationary communication platform for the observation of BANs which are significantly going to interact with each other. [66] presents a different possibility in which the diversity offered by the Multiple Input Multiple Output (MIMO) technology was utilized both to decrease the amount of distortion while also boosting the proportion of available channel capacity [57].

A simulated examination of interference in between BANs using same channel conducted at 2.45 GHz and 60 G Hz by [67]. With the assistance of a CAD (computer-aided design) prototype of an indoor site that is incredibly detailed was developed, a human body model that was made using the Poser7 software, and Using a comprehensive three-dimensional ray-launching simulator program, they were able to recreate a scenario successfully, According to the findings of the authors, on-body communications carried out at 2.45 GHz were particularly vulnerable to the effects of interference brought on by unwanted signals from other BANs in the vicinity. On the other hand, BANs operating at 60 GHz were able to mitigate co-channel interference in most instances. [57].

6. Conclusion

So far, research in the field of design and channel modeling for on-body, implantable, and ingestible antennas have been far from thorough. Many additional research avenues must be explored, and further improvement of antenna design and channel modeling processes may be achievable.

Further study on textile antennas and e-textile materials is necessary in the realm of on-body antennas before they can be employed for reliable transmission of medical data. Textile antennas must be treated in the same manner that we handle our daily clothes: washable electronics packaging, durable connectivity, and long-term behavior are all key difficulties that must be solved. Future designers will also need to concentrate on multifunction and multifrequency on-body antennas.

In the realm of implantable antennas, the trade-off between size and performance must be assessed and quantified. Electrically tiny antennas have poor radiation performance and a limited bandwidth. The design of multiband antennas, which wake up the implanted medical device when information exchange is required, is also important for conserving energy and extending the device's lifetime. When it comes to the planning and analysis of the performance of implanted antennas, it is essential to make use of simulation methodologies and tissue models that are both effective and precise. However, the most difficult aspect is carrying out experimental tests and taking measurements on real animals. In this area, paying close attention to detail is necessary in order to develop the most effective assessment framework. There has been little study into the construction of propagation models inside the human body, and channel modeling has only been done for certain scenarios with specific antennas and orientations.

The most recent findings in radio wave propagation and channel analysis and modeling for wbans are presented and discussed in this study. We looked at off-body, on-body, and body-to-body scenarios, as well as narrowband and ultrawideband channel models presented by different authors. We studied popular cases that are typically applied in the process of designing and assessing BANs in each specific circumstance, noting and commenting on the major variances that were found between the results. In addition to this, the most important aspects of modeling efforts that have been presented within the framework of modern wireless standards and cooperative efforts have been highlighted. In conclusion, we looked at a few problems that are still outstanding with channel attributes and that aren't sufficiently emulated by any of the current channel models.

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