# The Terahertz Channel Modeling in Internet of Multimedia Design In-Body Antenna

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## ABSTRACT

In this paper, the authors have emphasized on the perspectives of the Terahertz channel modeling in Internet of multimedia nano things (IoMNT) networks. A modulation technique targeting body-centric network is discussed. An analogy of a real Terahertz antenna is developed within a terahertz multi-layer modelling channel for a human skin tissue. As a result, the investigation of how signals at THz frequency band interact and transmit within the skin biomaterial. The human skin model used to collect data was selected to have four layers: epidermis, dermis, blood, and hypodermis, with the depth of the layers varying between normal human body values. It is revealed from the literature that the frequency and content have a substantial impact on path failure. The estimated path loss could thus differ considerably, but for a human skin model with depths of 0.21 mm, 1.23 mm, 1.38 mm, and 3.76 mm, the frequencies of 0.5-1.5 THz at the end distance resulted in a path loss estimated about 250-350 dB.

## KEYWORDS

Internet of Multimedia Nano Things, Internet of Bio-Nano Things, Nano Network, Terahertz Band

## INTRODUCTION

Mobile radio technologies began with low frequencies and progressed to millimetre-wave (mm Wave) methods, which are now used in 5G mobile communication networks. Furthermore, currently unused frequency regions greater than 300 GHz with wavelengths below 1 mm "(is known as THz frequency)" may permit mm-wave communications to evolve naturally in the future THz communication refers to wireless communication on these spectra, and it is seen as a viable solution for future high-data-rate communications beyond 5G for a variety of applications (Koenig et al., 2013) and (Kürner and Priebe, 2013). Wireless communication on these spectra is referred to as THz communication, and it is considered a promising solution to future high-data-rate communications beyond 5G for various applications. Researchers believe that the Terahertz (THz) band might be the main enabler for next generation wireless communication systems as to fulfill the requirement for terabit (Tbit) per second

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data speeds. Thus, terahertz channel modelling is a necessary and is a basic component to propagate the THz band wireless communication due to advancement in design of different THz device. Even though THz communication promises excellent performance, it is difficult to implement. Due to limitations in semiconductor technology, high-precision signal processing techniques and high transmission power cannot be implemented now. Moreover, despite its high carrier frequency, the THz channel suffers a substantial path loss, and its short wavelength results in a limited coherent distance, which means that the channel is highly sensitive to antenna displacements, making it difficult to implement dynamic applications. Given that multipath components (MPCs) do not overlap, the large bandwidth indicates frequency selectivity and good resolution in the delay domain. THz channels do not have the same channel characteristics as traditional Rayleigh and Rician fading channels. Furthermore, in recent study, the author has created a new model of the Terahertz band, which they explored through the channel power research, and they have explored the ability of this frequency band. In view of the specific features of the channel and the capabilities of the nano-machines, a series of communication mechanisms are developed for nano-network systems which comprise femtosecond pulse modulation, low weight channel coding schemes, a new symbol detection system for the receiver and the new nano-network medium access control protocol. The frequency range of wireless networking has increased constantly in order to accommodate the increasing demands for bandwidth (Nawaz et al., 2021) and (Sarieddeen et al., 2020). In the future generation (6G) and beyond, THz band communications (Akyildiz et al., 2014) and (Chen et al., 2019) significant function is anticipated, as millimetre-wave (mmWave)-band communication (Xiao et al., 2017) and (Rangan et al., 2014) are already developing in fifth generation (5G) mobile wireless communications.

## Problem Formulation and Potential Contribution

In the wireless nano communication different applications are explored and this paper focus on the biomedical application. There is a need for information to be transmitted timely and to be robustly shared over a nano network communication effectively. Fortunately, nano-transceivers of graphene and nano-antennas are required in the terahertz band to work indirectly (0.1–10 THz). Since established models of channels for lower rate bands cannot be reused for the terahertz band, as they do not capture several effects, such as molecular absorption attenuating and noise, particle dispersal similar in size to very short wavelength of terahertz waves, or terahertz radiation scintillation. Hence a need to investigate a way to design a new model for terahertz band communications. The size of nano devices allows them to be used in places out of reach to present disruptive technologies such as the environments exposed to harsh surroundings and likes of in body environment (Yang, 2016). This ability allows modelling a channel of communication within the THz band for the human body to monitor different diseases or the whole physical movement of humans. Specifically, in vivo body-centric communication system can be used. In this paper the body-centric communication channel is discussed for different body tissue, specifically 4 layers of skin models namely epidermis, dermis, blood, and hypodermis. This was done to test for different parameter involved in the type of channel model. Path loss due to spread, electrical field which is regarded as complex permittivity and the permeability are parameters of focus in this paper. The need to test out lower THz frequency band was a major concern as it's a range that is rarely explored. The authors potential contribution in this paper are as follows:

- Performing a multi-dimensional polynomial regression which used as a numerical analysis technique.
- An analogy of a real Terahertz antenna is developed within a terahertz multi-layer modelling channel for a human skin tissue.
- The path loss, noise, bandwidth, and channel capacity were among the properties that were investigated for different parameters explored in this paper.
- Block chain security perspectives for THz channel modelling are discussed in detail.

- Finally, potential research challenges in the IoMNT's networks and future research directions are presented.

## Organization of the Paper

"The remainder of this paper is organized as follows. Section II presents the literature survey on molecular absorption and path loss models for electromagnetic communication at the THz band. The design of channel noise model for in-vivo nano-networks is proposed with the consideration derivation of the model in section III. Section IV briefly presents the analysis and discussion part. Further, the potential research challenges in the IoMNTs networks are presented in the sections V. Finally, the entire work is concluded in the section VI".

## LITERATURE SURVEY

Multimedia nano-things also must communicate a vast volume of data in a timely and securely manner in lieu of effective data processing solutions and to work in a tacit fashion. Thankfully, graphene-based nano-transceivers (Sung, 2009), (Palacios et al., 2010) & (Jornet and Akyildiz, 2011) and nano-antennas are required implicitly to function in Terahertz Band (0.1-10 THz) (Jornet and Akyildiz, 2010) and (Rosenau da Costa et al., 2009). Terahertz band supports high bit rate data transfer, till multiple terabit/second (Tbps). But this frequency band is also among rarely investigated frequency bands in the electromagnetic (EM) spectrum. The Terahertz Band does not use current channel templates for the Megahertz and the Gigahertz Frequency Bands, as it does not catch many effects, such as a mitigation and molecular absorption noise, a particle dispersion similar in size to Terahertz's very weak waving waves, or a terahertz sparkling. The development of new nano-antennas (Jornet and Akyildiz, 2010) and (Zhou et al., 2005) also suggested for Nano-antennas and Nano-transceivers using graphene and derived materials of its own. Among other stuff, observed in (Kaviani et al., 2008) is that, owing to the special electron dynamics of this nanomaterial, only electromagnetic (EM) waves can be efficiently radiated by a 1 μm long graphene-based nano-antenna in the terahertz band (0.1-10 THz). This frequency spectrum is consistent with the operational frequency estimates for graphene-based radio frequency (RF) transistors and (Moon et al., 2011). More detail is given by (Akyildiz et al., 2015) which introduces the internet concept of the bio-nano things (IoBNT). IoBNT differs from as biological computers are incorporated into nano-things based on reengineered biological cells, whereas typical IoNT networks are: i) "artificial" implanted device and ii) electromagnetic signal-based communications. Notedly, following cell signage paths, IoBNT operates molecular communication. The intended applications of IoBNT are primarily intrabody sensing and actuation networks, and toxicity and emission environmental management. In the molecular connectivity and heterogeneous network interconnection phase, however several challenges are required. In nanotechnology-based technologies, security and privacy poses crucial challenges. Active control of terahertz source amplitude and frequency is required as a measure to a wide variety of terahertz applications in imaging, spectroscopy, and communications. THz innovations have developed rapidly in recent years because of the enormous growth of THz sources and applications hence more literature survey is discussed in Table 1. Terahertz transmission technology has been known advancement of various useful sources of THz radiation as a result of a notable increase in fantastic laser production over the last ten years. These sources have shown the potential of this technology in laboratories, as well as future advances. It is crucial to rapidly monitor the amplitude and frequency of the signals for the implementation of any possible THz communications network. Nano-networks are commonly agreed to provide several long-awaited smart healthcare to domestic defence, industrial growth, and conservation of the environment. The connectivity between nano-machines remains an important task (Dhillon et al., 2017). Security in nano communication is very delegate and needs to be explored further in the future designs of the health care nano communication systems. It is important to develop models that

**Table 1. Literature survey content of existing THz modelling**

| | Tittle | Description | Year | Authors |
|---|---|---|---|---|
| 1 | Terahertz electromagnetic field propagation in human tissues: a study on communication capabilities (Piro, et al., 2016). | Proposes a design of an electromagnetic field propagation in human tissues. However, the transmission of pulsed electric fields in a stratified media stack made up of stratum corneum, epidermis, dermis, and fat are proposed in this context. | 2016 | Piro, et al. |
| 2 | Channel modelling of human tissues at terahertz band (Abbasi et al., 2016). | Designs the Channel Modelling system of human tissue using THz band for different distances and concentrations. The results reveal that the THz band channel is highly influenced by the medium type and distance, while water concentration has a significant impact since it not only causes attenuation of the THz wave but also introduces non-white noise. | 2016 | Abbasi, et al. |
| 3 | Nano-sensor capacity and SNR calculation according to transmit power estimation for body-centric nano-communications (Akkaş, 2016). | Describes nano sensors propagating inside the human body and their capability and SNR (Signal to Noise Ratio). The THz (Terahertz) wave propagation model is based on the computation of route losses and noise level. According to the transmit power of the nano-sensor for future nano-communications inside the human body, the model also studies the channel capacity and SNR. | 2016 | Akkaş. |
| 4 | Cooperative in-vivo nano-network communication at terahertz frequencies (Abbasi et al., 2017) | Presents a new study on cooperative in-vivo nano network communication at terahertz frequencies for the first time in literature for their paper. They highlight body-centric nano-networks, like traditional body-centric communication, may be classified into three domains: on-body, off-body, and in-body which results in different attenuation when channel is designed. | 2017 | Abbasi et al. |
| 5 | Modelling of the terahertz communication channel for in-vivo nano-networks in the presence of noise (Zhang et al., 2017). | On the THz frequency range, their work focuses on the modelling of communication channel noise in human tissue (0.1-10THz). Using the physical process of channel noise in medium, researchers have developed a new model that takes into consideration both the medium's radiation as well as the molecule absorption from the signal transmitted. | 2017 | Zhang, et al. |
| 6 | Hybrid terahertz antenna design for body-centric applications (Abohmra et al., 2019). | In this paper, evaluation of the performance of a graphene-based THz antenna in free-space and on-body using three layers of human skin are explored. The use of short-range wireless communication was used. | 2019 | Abohmra, et al. |
| 7 | Survey of terahertz communication technology (Sha et al., 2020). | It introduces survey of the current research advances within THz technology, which includes channel modeling, channel measurement, channel estimation, communication scenario analysis and future research directions. | 2020 | Sha, et al. |
| 8 | 6G oriented wireless communication channel characteristics analysis and modelling (Hang et al.,2020). | This paper presents a detailed background study of channel modeling and channel sounding in 6G networks. | 2020 | Hang, et al. |
| 9 | Channel modeling and system concepts for future terahertz communications: Getting ready for advances beyond 5G (Guan et al., 2020). | Presents a promising solution that THz communication is facing at 300GHz and other different challenges likely to arise. The channel model documentation (CDM) is one of the standards solutions discussed. | 2020 | Guan, et al. |
| 10 | THz channel modeling: consolidating the road to THz communications (Guo et al., 2021). | Focuses on the latest literature for modelling THz the problems that also faces the terahertz modelling in the future. | 2021 | Guo, et al. |

have data integrity so that information does not become modified without authentication. In future security mechanisms can be incorporated to the designs of THz channel model communication especially on the physical layer.

## TERAHERTZ CHANNEL

The terahertz channel modeling requires electromagnetic nano- transceivers made out of graphene and operate within the terahertz band 100GHz to 10THz. To investigate the operation of these

frequencies the channel modulation model design was propagated using Debye relaxation model within the electromagnetic properties of human tissue. The path loss, noise, bandwidth, and channel capacity were among the properties that were investigated. Figure 1, show the main components of the skin layers used in propagating the channel. The measurements of the tissues concentrate on the 0.5-1.5 THz interval because of the constraints of current measuring settings. The channel modelling of human tissues at THz band includes different pathloss equations and other parameters which will be outlined in this section.

## Path-Loss Model

An electromagnetic wave in the Terahertz Band is obtained as the sum of the spreading loss and the molecular absorption attenuation (in dB) i.e., it spreads through a dispersing medium and will express the complete path loss as (Abbasi et al., 2016):

$$PL_{total}\left[dB\right] = PL_{sprd}\left[dB\right] + PL_{abso}\left[dB\right] + PL_{scat}\left[dB\right] \tag{1}$$

The path loss $PL_{total}$ due to spreading is $PL_{sprd}$, the path loss due to absorption $PL_{abso}$ and the path loss due to scattering $PL_{scat}$.

The path loss due to spread can be expressed more precisely as a wavefront propagates in space as a thinning of information. As an electromagnetic wave passes through a dielectric material part of the force of the wave is transferred into the vibratory material, which is the result of heat. Based upon the relative size and wavelength of the substance molecules of the electromagnetic wave, various kinds of dispersion exist. The frequency is higher than most molecules in the body of terahertz wavelengths which ensures the Rayleigh spreads. As the wavelength of the Molecular is too great, this dipole would in fact start to oscillate with the electromagnetic wave, which lets the dipole radiate force as a dislocation, since there is a continuous electric field, which causes the dipole to grow as a dipole in its molecule. (Elayan et al., 2017) show that previous study has discusses the in comparison to the other path loss variables, the results of dispersal are marginal within terahertz and the equation (1) can be simplified as (Yang et al., 2015):

**Figure 1. A cross-section human-skin layers structure of labelling (https://www.alamy.com/search/imageresults.aspx?qt=skin+layers)**
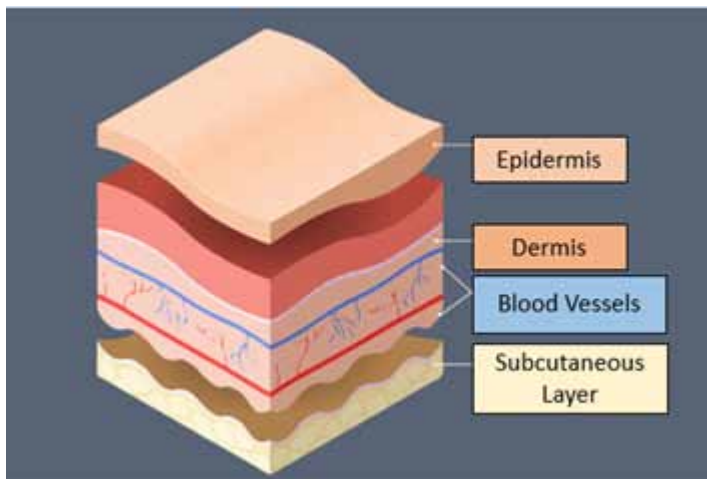
$$PL_{total}\left[dB\right]=PL_{sprd}\left[dB\right]+PL_{abso}\left[dB\right] \tag{2}$$

Moreover, progressing from one medium to a stratified media stack, we have to add path losses due to interface boundaries reflectance $PL_{ref}$ and hence the equation can be written as (Pettersson, 2018):

$$PL_{total}\left[dB\right]=PL_{sprd}\left[dB\right]+PL_{abso}\left[dB\right]+PL_{ref}\left[dB\right] \tag{3}$$

The loss of the spreading path can be expressed by means of the popular Friis transmitting formulation, which relates the loss of space, antenna gains and wavelength to the obtained transmit powers (Jornet and Akyildiz, 2010):

$$PL_{sprs}=\left(\frac{\lambda_g}{4\pi d}\right)^2 \tag{4}$$

In this above equation the directivity of transmitting antenna relative to an atmospheric antenna is D, the distance covered by the wave is d. The effective wavelength can be derived as $\lambda_g = y / n'$ where n is the refractive index of the medium which can be separated into its complex parts as $n = n' - n''$. The directivity refers to the maximum gain of the antenna and can be calculated by dividing the maximum power density, $P_{max}(\theta;\varnothing)$ ), by its average, $P_{av}\left(\theta;\varnothing\right)$ over a sphere observed in the far-field of the antenna, (Elayan et al., 2017) i.e.:

$$D=\frac{P_{max}\left(\theta,\varnothing\right)}{P_{av}\left(\theta,\varnothing\right)} \tag{5}$$

The attenuation due to absorption of an electromagnetic wave passing through a dispersive medium can be calculated from the Beer-Lambert law as:

$$PL_{abs} = e^{-\mu_{abs}d} \tag{6}$$

An attenuation coefficient due to the dispersive media absorption is $\mu_{abs}$, which is based on the medium's special molecules absorbing radiation. It was first derived and calculated by (Jornet and Akyildiz, 2010), and owing to the nanoscale configurations of human tissue the same technique could be used in the body. The coefficient can be calculated as (Abbasi et al., 2016):

$$\mu_{abs} = \frac{4\pi n''}{\lambda} \tag{7}$$

The losses of reflection at boundary interface the crossroads can be determined by the Fresnel equations for a non-magnetic medium as no magnetic properties were found to be present in the terahertz field of human tissues (Jornet and Akyildiz, 2010):

$$PL_{ref} = \frac{n_1' - n_2'}{n_1' + n_2'} \qquad (8)$$

with $n_1'$ and $n_2'$ being the refractive index of the medium the wave is propagating from and to, respectively.

## Parameters

The human tissue behaves as a dielectric, meaning that the charge cannot be transported like the metal, but even electric fields can spread. This means that the complex permittivity of human tissue can be shown as (Bia, et al., 2016):

$$\epsilon_r = \epsilon_r' - i\epsilon_2'' \qquad (9)$$

Since human tissue has no magnetic properties, the magnetic permeability $\mu_r$ is approximately equal to unity and the refractive index can be simplified as (Pettersson, 2018):

$$\eta = \sqrt{\epsilon_r \mu_r} \approx \sqrt{\epsilon_r} \qquad (10)$$

The human tissue contains biomedical nanostructures, which primarily include water molecules, so that various dielectric relaxation approximations can be used to precisely model the necessary material properties on the terahertz frequency band. The Debye model is the simplest and is defined as (Elayan et al., 2017):

$$\epsilon_r = \epsilon_\infty + \sum_{k=1}^{n} \frac{\Delta\varepsilon_k}{1 + i\omega T_k} \qquad (11)$$

Here signifies each different relaxation process is signified by k, the permittivity at the high frequency limit $\Delta\epsilon$ , is the permittivity difference between each relaxation process (for only one process $\Delta\epsilon = \epsilon_s - \epsilon_\infty$ , where the static permittivity at the low frequency limit) is $\epsilon_s$ , the characteristic relaxation time relating to that specific process is $T$ and $\omega = 2\pi f$ is the angular frequency. The Debye model can be rationalized to its real and imaginary parts as (Elayan et al., 2017):

$$\epsilon_r = \epsilon_\infty + \sum_{k=1}^{n} \frac{\Delta\varepsilon_k}{1 + (\omega T_k)^2} \qquad (12)$$

$$\epsilon_r'' = \frac{\Delta\varepsilon_k \left( (w T_k) \right)}{1 + (\omega T_k)^2} \qquad (13)$$

The Havrilak-Negami model also includes the asymmetry and width of the dielectric dispersion curve, another version of the Debye model (Piro, et al., 2016):

$$\epsilon_r = \epsilon_\infty + \sum_{k=1}^{n} \frac{\Delta\varepsilon_k}{\left(\left(1 + i\omega T_k^{\alpha}\right)^{\beta}\right)} - j\frac{\sigma}{\omega\epsilon_0} \tag{14}$$

where the ionic static conductivity $\sigma$, $\varepsilon_0 \approx 8{:}854{*}10^{-12}$ Fmis$^{-1}$ the free space permittivity and $\alpha$ and $\beta$ is heuristically derived power law exponents. The Havrilak-Negami model can also be rationalized into its real and imaginary parts as (Pettersson, 2018):

$$\epsilon_r' = \epsilon_\infty + \Delta\varepsilon_k(1 + 2(\omega T_k)^{\alpha}\cos(\frac{\pi\alpha}{2})(\omega T_k)^{2\alpha})^{-\frac{\beta}{2}} \cdot \cos\beta\phi_k \tag{15}$$

$$\varepsilon_r'' = \Delta\varepsilon_k\ (1 + 2(\omega T_k)^{\alpha}\cos(\frac{\pi\alpha}{2})(\omega T_k)^{2\alpha})^{-\frac{\beta}{2}} \sin\beta\varnothing_k - \frac{\sigma}{\omega\varepsilon_0} \tag{16}$$

with $\varnothing_k$ being a constant defined as:

$$\varnothing_k = \arctan\frac{(\omega T_k)^{\alpha_k}\sin\pi\alpha_k\,/\,2}{1 + (\omega T_k)^{\alpha_k}\cos\pi\alpha_k\,/\,2} \tag{17}$$

### Instantaneous Power

In a case of the real antenna design there is a need for instantaneous power calculation to be able to determine the performance of the antenna and its efficiency in relation to the channel that would be developed. The instantaneous power received by the antenna is defined as follows (Pettersson, 2018):

$$P = P_{density}A_e \tag{18}$$

where the power density is $P_{density}$ and the effective aperture of the antenna $A_e$. The power density in a propagating wave point can be determined using (Pettersson, 2018):

$$P_{density} = \frac{|E|^2}{2Z} \tag{19}$$

and $E$ is the electric field, $Z = Z_0\sqrt{\epsilon_r\,\mu_r}$ is the wave impedance, with $Z_0 \approx 377\Omega$ as the free space wave impedance. In addition, the effective aperture of an infinitely small antenna is expressed as follows (Pettersson, 2018):

$$P = \frac{P}{P_{anntena}} \tag{20}$$

In comparison with the power of the transmission antenna, can then use equation. (3.18) to quantify the direction loss for an arbitrary point in a propagating wave as (Pettersson, 2018):

$$A_e = \frac{\lambda^2}{4\pi}$$ (21)

In order to investigate the in vivo wireless communication channel, accurate body models, and knowledge of the EM properties of the tissues are crucial.

Pseudocode on how the proposed channel model in the literature is propagated is as follows:

- Choosing parameters used to approximate the permittivity of different human tissues at the early terahertz band (0.1-1.5 THz).
- Set function presentation for the model design using the double relaxation Debye equation and either the single or double Havrilak-Negami relaxation equation to propagate the channel model.
- Electromagnetic field propagation in human tissues: Dermis, Hypodermis, Blood and Epidermis.
- Set the variable index used to determine what kind of approximation will be used determine the permittivity.
- Set a function to create a polynomial that approximates the path loss model of the function and can be used to compare against many other such data sets.
- Choose the data sets that will be used for the polynomial extraction.
- Set declaration for the frequency and distance.
- Set the variables to perform the multivariable polynomial extraction.
- Perform the extractions.
- Set polynomial coefficients in other variables.
- Initialize of constants and frequency conversions at different distances.
- Calculate the path loss using numerical analysis.

The pseudocode can be modeled into the working channel model through coding using the MATLAB simulation to determine the permittivity at different frequencies specifically lower ones.

## ANALYSIS AND DISCUSSION

The permittivity can be determined for frequencies from 0.5-1.5 THz with the use of the values of Table 2 and with the respective equation of each eq.(12, 13, 15 & 16). A real part and imaginary parts of the permittivity of the four-layer human skin mode can be constructed in this sense. Importantly there is a slight difference in the graphs that can be expected either a less permittivity or the differences in the lines would mark the overall path loss results accordingly.

The overall path-loss for a Terahertz traveling wave is defined as the increase of the spreading loss and the molecular absorption loss (Jornet and Akyildiz, 2010). The spread losses are caused by the wave expanding as the medium spreads and depend on the frequency and the transmission distance. The loss of absorption results in a decrease in the molecular absorption of a traveling wave, i.e., the process by which part of the wave energy is transformed, into internal kinetic energy to certain

**Table 2. 4th order coefficients for the two-dimensional polynomial (Pettersson, 2018)**

| | | | | | |
|---|---|---|---|---|---|
| $d^4$ | - 0.7475 | $d^3f$ | -0.2915 | $d^2$ | 0.2665 |
| $d^2f^2$ | 0.7177 | $d^2f$ | 2.6268 | $d^3$ | -48.0738 |
| $df^3$ | 2.5147 | $df^2$ | -17.3197 | $df$ | 29.4830 |
| D | 110.9589 | -15.5318 | | $f^4$ | 70.7033 |
| | | | | $f^3$ | |
| $f^2$ | -118.0479 | $f$ | 96.8260 | Constant | -19.0850 |

molecules located in this channel (Yang et al., 2015). In a practical example loss can be observed across different distances in the captured results. The spreading path losses across all distances for 0.5,1.0 and 1.5 range in THz can be simulated for desired skin layers.

In a practical example from literature (Pettersson, 2018) path loss of the spread seems to be not quite material based since only a few dB vary from each other over great distance for different materials.

Hence, the general observation is that the loss of absorption is much larger than the loss of dissemination. The reflection for these unique limits can be expected up to 1.6%, which is less than 0.1 dB unlike the 3dB which can be anticipated in the design of any THz channel modelling. Equation 1 is very useful to in denoting the overall direction for the losses present it.

Overall, when designing channel of a four-skin layered model the total path loss for an electromagnetics signal through an electromagnetic stack of 6.58 mm of human tissue can be expected to be affected from 0.5 to 1.5 THz frequency spectrum which in between 300-375 dB. For validation and accuracy of the channel model it is important to perform polynomial regression using a number of coefficients to realize a two-dimensional polynomial.

Moreover, it is worthy to perform the polynomial regression in system modelling since it is important for statistical process in estimating the relationship of dependent variable to one or more independent variables. In performing regression, the series of data set of path loss program from MATLAB can be ran using a multidimensional polynomial regression function. The polynomials can be determined to be in 4th order and based on two factors, frequency, and distance. The datasets for the regression of the polynomial can be built on a human skin with a continuous total depth of 6.6 mm. The randomization of values for epidermis should be considered from 0.5 to 1.5 mm, dermis from 3 to 4 mm and blood from 0.5-1 mm. The hypodermis layer can set be cover a constant depth of 0.1-2.6 mm. In this way more accurate results can be expected as in different channels explored by different authors.

The aim of the polynomial is to assess points from which the data sets have been generated in one set. The polynomial can be constructed using the Table 2 coefficients which would result in the same figure with the total path loss against both frequency and distance for the 4-layer human skin model. A major difference of different data sets should be noticeable especially in the interface borders relative to those random data sets. For better accurate results while performing polynomial regression more data sets need to be compared.

In doing the channel propagation different simulation tools are used and all uses a different approach to perform task. Other simulation software materials use Maxwell's equations to numerically measure wave propagation, while the MATLAB package uses analytical expressions that are not related to Maxwell's equations, so certain inconsistencies are possible but can use a Debye Model to contrast to Maxwell's equations.

For the multi-layer analogy, the two curves anticipated become very similar at longer distances, which indicates that the model has some hope, but the fact that the models swap positions for short distances is unusual since it expected for them to behave the same as in the single layer situation, except for possible reflections at interface borders, which are anticipated to be very minor. A half-wave dipole antenna with a gain of 2.15 dB can be used in designing a THz channel model because of its code convenience in MATLAB. It can also be used for comparative purposes; it is not used for any nano-antennas that authors are aware of. In terms of the MATLAB program, it should be noted that the model is sensationalized in a variety of ways. The human skin is much more complex than what the authors understand here, with all of its components, including hair follicles, glands, capillary networks, and even sweat ducts, having electrical properties that impair the transmission of electromagnetic waves (Heyden et al, 2010). Using whole blood measurements to describe a blood vessel is also unlikely to be realistic, since vessel walls are very porous and may have more skin-like characteristics than the very marine whole blood. These distinctions, however, have little bearing on the contrast of the MATLAB program, just against the actual solution. The model does not consider any multi-path opportunities, just a signal propagating in a straight line with full losses in interface

reflections. The model also suggests that the antenna is still pointing outwards from the skin. This might not be so likely if the devices are diffusing within the human body, unless the authors imagine a vast network of nano-machines in which the expectation of always one being in the appropriate path rises. All of these effects are potentially minor, but they all contribute to the model's lack of realism.

In designing a THz channel model, it is important to perform numerical analysis. The aim of the numerical analysis is to find a straightforward equation that could be "carried around" so that there's no need for any tools hence making it easy to find an answer to a path loss problem anywhere on the human skin. Retaining the polynomial at the fourth order is considered by different authors because growing the order does not dramatically increase the precision of the polynomial and going down to a third order model nearly doubled the average error. Similarly, the decision to use various data sets is focused on accuracy; there were no major improvements when increasing the value to 20 or 30, so 10 seemed adequate in (Pettersson, 2018). The decision to limit the tissue depths works in favor because it regarded to reduce the uncertainty of the outputs, increasing the probability of the data sets used. This suggests that the narrower the tissue depths, the greater the precision of the polynomial, but it defeats the intent of being used anywhere on the human skin. The polynomial mean error of 4.08% across 90 data sets can be expected when designing a THz channel model, but the individual deviations could be up to 40 dB in a single stage, which would be too much for any accurate data to be extracted.

A multi-dimensional polynomial regression is more accurate and is discussed as numerical analysis technique in this paper. A stronger interpolation technique, ideally one that considers the depth of each particular layer rather than only the overall depth, will greatly improve the final outcome. Despite the fact that all existing calculations are based on the low terahertz band (0.1-2 THz). It would be important to investigate what happens at higher terahertz frequencies as well, particularly because it has been demonstrated that water molecules undergo hindered longitudinal and rotational motion within those regions [36], altering its dielectric properties. Another fascinating factor to explore is whether heat expulsion due to high absorption of human tissues complies with current safety laws, as heating can have serious consequences for the human body, although to my knowledge, only one article has looked into it [36]. The real findings of this study based on the literature show that the requirements for wireless communications within human tissue at terahertz frequencies are utterly horrendous, with attenuations of many hundred decibels occurring after just a few millimeters. This confirms the concept of several nano-machines forming a body-centric nano-network in order to generate a signal. Not just that, but there must be well-thought-out, rigorous physical layer algorithms in place in order for this technology to be realized. In conclusion, THz modelling channels can be implemented for the betterment of communication within the human body in the application of the health fraternity. The modelling of THz band channels contributes a very important role in making sure that communication is effective within the nano communication network which is proven in the analysis of discussion of this research.

## SECURITY AND BLOCK CHAIN PERSPECTIVES IN THZ CHANNEL MODELLING

The security in the next generation communication and society systems is of prime importance and the case is same for the THz channel modelling designs, therefore it is worth and required to address the security issue. The potential security concerns are data-integrity, audibility and non-repudiation (Khan et. Al 2018). Data integrity is defined with reference to the unauthorized changes in the data. The attacks come under the category of data-integrity attacks are such as: deliberately corrupting the original information by using some malicious gains. This corruption of information leads to the major concerns in particular data critical applications such as THz medical imaging application, or THz communication applications for vehicular, healthcare, or robotics application. The next attack is non-repudiation and defined with reference to the protection against false denial of involvement in a network. With the introduction of IoTs and machine type communication where THz communication is

finding its important place the chances of repudiation attacks are there. Audibility is also an important security feature and defined as the ability to reconstruct the entire history of certain events from the historical records available. In many Large-scale connected autonomous systems applications where critical decision making is involved, auditability would be required to fix liability in case of malfunctions, conflicts, or to safeguard commercial and financial interests. "Blockchain security is achieved via the implementation of cybersecurity frameworks, security testing methodologies, and secure coding practices to protect a blockchain solution from online frauds, breaches, and other cyberattacks". THz beams are more directional when compared with the lower frequency beams therefore, block-chain appears to be a potential and more appropriate security techniques for THz

**Table 3. THz channel modelling challenges in IoMNT**

| Challenges | Definition | Comparison |
|---|---|---|
| Security | Security is more vulnerable within THz channel modelling when transmitting data that's captured. | The design of THz channel modelling still uses security technology of which does not capture all data hence a new design should have a mechanism that is able to authenticate to transmit securely over a network (Guo et al., 2021). |
| MAC Protocol | MAC protocols since the current Medium Access Controls cannot be used in the used in the IoMNT for THz channel modelling design. | Current MAC have limited functions in capturing the particularities of the physical layer and the greatest heterogeneous competencies of all kinds of nano-things. There is a need to establish a MAC protocol that chooses the modulation system dynamically and ensures that the sender and the recipient are matched correctly before a data packet can be sent (Tekbiyik et al, 2020) and (Solyman et al., 2021). |
| Addressing | It is not a simple task in IoMT to provide another address to all nanotechnologies, mostly because these addresses should be assigned separately at the production level, or complicated protocols of synchronization and communication between nanotechnologies should be utilized. | Considering that the IoMNT could incorporate a very large number of nano-things and addresses very long raise necessity to adopt conventional approach systems. The solution is prominently needed to address this issue within a network by generating different approaches to capture and use the hierarchy of networks in IoMNT and allowing big data handling (Zhao et al., 2020). |
| THz Channel Modelling | Multimedia nanotechnologies are still to relay very large quantities of data promptly and reliably despite the effective data transmission solutions. | Terahertz Band cannot reproduce already generated channel patterns for the Megahertz and Gigahertz Frequency Bands, because they do not capture many impacts such as molecular absorption noise and attenuation, particle scattering that is compared with the very short terahertz wavelength or terahertz scintillation. The need to design several windows to ensure Tbsp connect to IoMNT for high transmitting rates (Koenig et al., 2013). |
| Discovery and Routing | The characteristics of the Terahertz Band channel also influence the technique of network layer solutions for IoMT on how it must be created. | Existing designs do not use neighbour discovery routing hence a need to effectively meet THz channel modelling network functionalities to attain the best performance in the network matrices to allow easy discovery over the map-based channel. New strategy in neighbouring exploration leverage Terahertz's high direction to locate the relative place and orientation of nano things (Ferrand et al., 2016). |
| THz Electronics Design | Progress is slow in THz communication because of "THz Gap" which arise because of unique technical challenge with signal generation. | To improve the progress the improved oscillators should be designed for novel antennas used in channel modelling (Jornet and Akyildiz, 2013) and (Alsharif et al., 2020). |
| Support for Node Mobility | Peers within a communication network need to be mobility enabled. | Focusing on the issues of antenna gain, it's not easy to ensure the tracking of the already established beam configuration for mobile devices and THz channel models. It is merely important to adapt to common beamforming training approach to THz frequencies (Alsharif et al., 2020). |
| QoS | Medium Access Control and Routing solutions rely strictly on Terahertz channel features such as the special relationship between the 3dB bandwidth of each Terahertz channel, the communication distance, and the transmission windows the directiveness of the antenna. | To achieve maximum efficiency in various network metrics, it is essential to jointly optimize all these network functions (e.g., physical layer, MAC, routing). The best modulation is to use the available 3dB bandwidth can be used to make an effective use of the Terahertz Band channel, considering the basic capabilities of the nano elements involved in each connection (Alsharif et al., 2014) and (Piro et al., 2016). |

channel modelling. The security perspectives in the THz channel modelling are in toddler stage and complety unexplored using blockchain security techniques. Therefore, it is a potential research area in the field of THz channel modeling.

## POTENTIAL RESEARCH CHALLENGES FOR THZ MODELLING IN IOMNT NETWORK

For the wireless architecture of THz communication networks either within the IoMNT application or on its own, there are a range of problems, which must be researched and solved to construct functional systems. The complexities and new approaches to addressing the challenges facing the future design within the THz channel modeling in Internet of Multimedia Nano Things are addressed in this section. There is still a room for improvement in the existing designs for THz channel models. The major challenges include THz channel modelling, Security, Quality of Service (QoS), Medium Access Control, Discovery and Routing, Addressing, THz Electronic design, Support for Node Mobility, Beamforming, Sensing, THz nano-transceivers, THz Amplifiers THz antenna Arrays etc. A brief summary is discussed in table three for better understanding of what these challenges are and how they affect current THz channel modelling within the IoMNT.

## CONCLUSION

The research brought about more insights on how the application of nano communication within the IoMNT in its diverse environment can be applied. In this specific paper the design of Terahertz band channel modelling in Internet Multimedia of Nano Things is defined. A novel propagation model for the total path-loss and system noise was utilized to describe the terahertz channel. Depending on the distance and the different power distribution systems, the high-frequency selective terahertz channel has the channel capacity. As a result, the channel model for THz band communication in relation to the human skin through an assumption of nano communication via a transmitting signal imagined to be transferred from the wearable digital gadget tagged on an individual's arm was designed. The model in [34, 43] considered spreading, absorption, and the reflection as the dielectric for the independent losses propagated within the channel. This proposed design model is an excellent starting point for further research the comprehension of in-vivo channel models and nano-communication. Regarding the polynomial interpolation, it is less robust to be used in any realistic circumstances, but it does have a general idea about how the path loss in human skin appears at these frequencies. The proposed technique from literature has potential of deployment in modern THz systems to achieve high performance hence further direction in exploring high THz frequencies in-vivo communication within the health field in nano communication and the physical principles and mathematical derivations of the body radiation.

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