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SPATIAL MODELING OF THE TRANSMISSION CHANNEL FOR THZ RADIO COMMUNICATION SYSTEM

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Due to the growing demand for high speed wireless communication systems, it is crucial to look for new technology that can support this need. Indeed, THz technology has the potential to provide high data rate and multimedia applications for wireless communication system. In this paper, we evaluate the channel impulse response and the channel transfer function of terahertz system. The objective of this work is to propose an appropriate channel model for the THz bands. For this reason, we build a static model based on the existing Saleh-Valenzuela model. we have modified this classical model to adapt it to the THz context. The proposed model takes into account propagation losses and multipath propagation to provide designers with the impulse and frequency response of the channel, as well as their variations over time for mobile channels. Simulation results have shown that the distance between transmitter and receiver play a major role. Besides, multi-path effect introduces notches in the channel and create bands in which the channel become more selective. Moreover, the increase in the carrier frequency lied to a high path loss. These issues produce inter symbols interference which affect the performance of overall system. Therefore, to simulate an entire system including transmitters and receivers we should take into account this bands in order to get good reliability.

Keywords: Multi-path Component, Path Loss, Channel Modeling, Transfer Function, THz System

1. Introduction

The history of wireless communications systems dates back to the 1880s, when Hertz demonstrated that electromagnetic waves could propagate without hardware support. In 1892, the work published by the Englishman Sir Williams Crookes predicted the feasibility of long-range telegraph communications using adjustable devices [1]. Because of their high throughput, wireless communications systems are becoming dominant elements in data communication. Indeed, the systems can be used to transmit the information necessary for applications such as monitoring, remote control of equipment, routing, texts, images, videos in real time, production management or to provide a means of communication between two devices. Therefore, the wireless network that will be established must have

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significant capacity to support the activities mentioned above. By using new high-speed technologies such as THz technology, these high-speed needs can be met [2, 3].

A transmission channel provides the link between the transmitter and the receiver by allowing the transfer of information between the two parts [4, 5]. For this, the transmission channel plays a major role in a communications system, since it is one of the obstacles to the reliable transmission of information. The study of the propagation of signals is usually done based on the modeling of the propagation channel. Many research has been carried out in order to propose a mathematical model for THz channel. In [6], Tsujimura et al. propose a time-domain channel model for THz band (0.1– 10.0 THz) by given an impulse response. An alternative modeling approach is to reproduce the observed impulse response at a precise position of a given environment by statistical tools [7]. Fu et al. propose a model of this type for THz bands [7]. In [8], a polynomial LOS channel model has been proposed for THz bands. This model is valid in the frequency band from 100GHz to 450 GHz. Zhang et al. Have provided in [9], a review on channel modeling THz applications. The view for 6G channel models is also debated. In [10] a Channel Model for Microscale Terahertz Communication has been carried out. In addition, Gougeon et al. propose a deterministic modeling in LOS situation, capable of reproducing coherent spatial variations [11]. A linear progression of the clusters is thus observed when the receiving antenna moves. Other proposals have been made regarding the modeling of the THz channel in the frequency domain, such as the case of the work published in [12]. In [12], a frequency channel model is proposed based on the measurements of channel transfer function. The proposed model takes into account the phenomenon of 'Clustering' to characterize the propagation channel in THz bands. NLOS (Non-Line of sight) and LOS (Line of sight) components are discussed in the latter work. Besides, the high level of oxygen uptake and path attenuation significantly reduce the range of THz communication systems [13, 14], but this has the advantage of reducing interference between systems and thus allowing spectrum reuse in a different room and thus better resource exploitation and increased security in data transmission. In [15], an investigation on the impact of atmospheric absorption in a THz bands on both frequency and time domain are carried out. It has been demonstrated that losses increase with frequency and with distance. This analysis was done in both frequency and time domains.

The aim of this paper is to propose a complete model for the THz bands. A complete model takes into account propagation losses (largescale fading or large-scale effects) and multipath propagation (small-scale fading or small-scale effects) must be established to provide designers with the impulse and frequency response of the channel, as well as their variations over time for mobile channels. Models must be realistic and of low complexity in order to limit calculation times. To do that, we built a static model based on the existing model of the wireless channel. The basic model used in this work is the Saleh-Valenzuela channel model. we have modified this classic model to adapt it to our context. For this purpose, we have introduced the special variation, the atmospheric absorption as LOS component and the multi-path effect as NLOS component, and then merging them with the classical Saleh-Valenzuela model. The model proposed in this work is adopted in time to suit any application in the band allocated to THz system. Simulations results are given to validate our model and to show the impact of channel parameters such as multi-path effect, propagation loss due to distance and atmospheric absorption on the channel transfer function and total path loss.

2. Problem statement

Due to the multipath nature of the wireless channel, the signal transmitted on this type of channel degrades rapidly and randomly over short distances or periods of time. These rapid and random variations cause the received signals to arrive at Rx with different propagation delays, phases and even amplitudes [16]. For this reason, studies have been done to propose better models for wireless communication systems. On the other hand, given the random nature of this multipath propagation, we can associate it with a random impulse response channel. Indeed, without going into detailed explanations of the definitions, propagation losses include several parameters that make it possible to evaluate the power losses from a transmitter to a receiver. The main parameters are the power-delay profile as a function of distance $Pr \propto D^{-n}$ In the case of free space propagation n is equal to 2. The power-delay profile is given by:

$$\mathrm{PL(D)} = 10\mathrm{n}\log_{10}\left(\frac{\mathrm{D}}{\mathrm{D_0}}\right) + \mathrm{PL(D_0)} + \varsigma_\sigma \quad (1)$$

In this work, we will first calculate the impulse rethinking of the channel and deduce the propagation losses. To do that, we use the following equation:

$$\mathrm{PL(D)} = \frac{1}{\mathrm{N_{DFT}}}\sum_{\mathrm{m}=1}^{\mathrm{N_{DFT}}} |\mathrm{H(f_i, D)}|^2 \quad (2)$$

For each frequency band and for each scenario a curve was obtained. Then the time-dispersive behavior should be evaluated. The average power profiles received as a function of PDP(τ) delays were first extracted from impulse response:

$$\mathrm{PDP(t_0)} = \frac{1}{\mathrm{N_T}}\sum_{\mathrm{m}=1}^{\mathrm{N_T}} |\mathrm{h(t_i, t_0)}|^2 \quad (3)$$

Where $\mathrm{N_T}$ represents the number of paths at each $\mathrm{t_i}$ moment. The variable $\mathrm{t_0}$ indicates the delay corresponding to multiple path.

To study THz wireless communication system, the channel response is required. To realize this requirement, the frequency and the impulse responses of THz channel must be studied. Indeed, the first issue associated with THz communication system is due to atmospheric absorption [17]. The multipath effect, is another challenge in the THz bands that leads inter-symbol interference (ISI) [17]. There exist numerous channel models for THz, which describe the frequency domain [18]. In [19] an appropriate channel model for examining THz wireless channel among nanodevices in the THz band is given. Moreover, it has been demonstrated in [20] that the reflection characteristics caused by the channel depend on the material. Furthermore, a multipath THz channel model including both LOS and NLOS configuration has been proposed in [21].

3. THz channel model

During its transmission, the radio signal passes through the channel, which acts as a linear filter. So, we can characterize a channel by studying its impulse response. Considering the transmitter or receiver in movement, the expression of the impulse response $\mathrm{h}(\mathrm{d},\mathrm{t},\tau)$ is expressed as :

$$\mathrm{h}(\mathrm{d},\mathrm{t},\tau) = \sum_{\mathrm{l}=1}^{\mathrm{N}} \sum_{\mathrm{k}=1}^{\mathrm{R_l}} \hat{\mu}_{k,l}(t) \mathrm{e}^{\mathrm{j}\lambda_{\mathrm{k,l}}(\mathrm{t})} \delta(\tau - \mathrm{T_l} - \Delta\tau_{\mathrm{k,l}}(\mathrm{t})) \qquad (4)$$

Where $\mathrm{h}(\mathrm{d},\mathrm{t},\tau)$ is the time-varying impulse response t of the channel, τ is the delay experienced by the signal in the channel and d the distance that separates the transmitter from the receiver. Thus, N presents the number of paths discernible by the receiver. Each discernible path can be modeled by an amplitude $\hat{\mu}_{k,l}(t)$ and a phase shift θ_l associated with the delay τ_l. At high frequencies, some frequencies are absorbed by oxygen or water vapor. Oxygen thus absorbs a number of lines that are found at high frequencies. Due to this, the absorption coefficient must be taken into account in to model the transmission channel. For this, $\hat{\mu}_{k,l}(t)$ will be expressed as :

$$\hat{\mu}_{k,l}(t) = \mu_{1,1}^{2} \frac{c}{4\pi f d} \exp\left(-\frac{1}{2}\gamma(f, T_k, p) d\right) e^{-\frac{T_l - T_1}{\rho}} e^{-\frac{T_l - T_1}{\gamma}} \qquad (5)$$

Where $\gamma(f, T_k, p)$ is the molecular absorption coefficient [14], ρ is the inter-cluster of the different radius and γ is the intra-cluster of the different radius.

3.1. Merging loss component in the proposed model

The first stage in the construction of the THz channel model concerns attenuation due to signal propagation. Our propagation loss model will be expressed as follows in dB :

$$\mathrm{PL}(f, d) = 10\mathrm{n}\log_{10}\left(\frac{\mathrm{d}}{\mathrm{d_0}}\right) + 20\log_{10}\left(\frac{\mathrm{f}}{\mathrm{f_0}}\right) + \mathrm{PL}(\mathrm{f_0}, \mathrm{d_0}) + \varsigma_\sigma \qquad (6)$$

The random variable ς_σ translates the slow variations of the propagation channel in dB, related to the irregular masking phenomenon. We recommend modeling it by a Gaussian variable of zero mean. The attenuation model is therefore governed by 3 parameters: the coefficient of losses by propagation in distance n, the standard deviation σ of the variable ς_σ and the attenuation at an arbitrary frequency and distance $\mathrm{PL}(\mathrm{f_0}, \mathrm{d_0})$. The values of $\mathrm{PL}(\mathrm{f_0}, \mathrm{d_0})$ are given for $\mathrm{f_0} = 300GHz$ et $\mathrm{d_0} = 2m$.

3.2. Merging the frequency selectivity in the proposed model

We have seen previously that the THz channel is a multipath channel. Therefore, we need to take into account this phenomenon in the design of the channel module. For this purpose, we will propose the module shown in Figure 1. We will play on the value of τ to create the multi-path aspect.

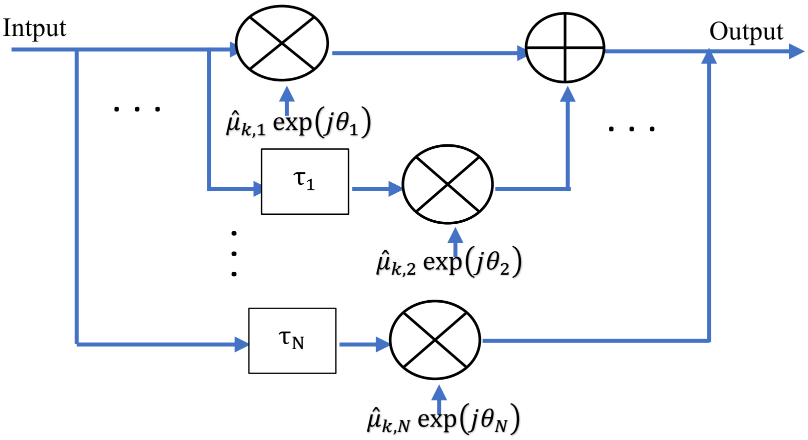

Figure 1: Generation of multipath channel component

Thus, the higher the value of τ, the more frequency-selective the channel will be. So this model has a high degree of freedom. In the case of N paths, the impulse response of the proposed model is represented by :

$$h_{MP} = \hat{\mu}_{k,1}\exp(j\theta_1)\,\delta(t) + \hat{\mu}_{k,2}\exp(j\theta_2)\,\delta(t-\tau_1) + \cdots + \hat{\mu}_{k,N}\exp(j\theta_{Na})\,\delta(t-\tau_{N-1}) \quad (7)$$

where $\hat{\mu}_{k,1} \ldots\ldots \hat{\mu}_{k,N}$ are two independent Gaussian random variables, $\theta_1 \ldots . \theta_N$ are random variables with uniform distributions between [0, 2 π], and τ_l is the delay. By varying τ_l, it is possible to create frequency-selective fading effects. This modeling is based on a description built on a set of clusters. Clusters are characterized by exponential power decay, i.e. linear decay for a dB representation. The arrival times of clusters and rays of each cluster are governed by a random process of Poison. By setting $\hat{\mu}_{k,1} = \cdots = \hat{\mu}_{k,N} = 0$, we obtain the special case of a non-frequency selective Rayleigh fading channel:

$$h_{MP} = \hat{\mu}_{k,1}\exp(j\theta_1)\,\delta(t) \qquad (8)$$

3.3 Merging spatial characteristics in the proposed model

The performance of an antenna system depends, generally, on the angular probability density of the powers following the θ and φ polarizations . These densities can be treated separately in elevation and azimuth as follows:

$$P_\theta(\theta,\varphi) = P_\theta(\theta)P_\theta(\varphi) \quad (9)$$

$$P_\varphi(\theta,\varphi) = P_\varphi(\theta)P_\varphi(\varphi) \quad (10)$$

Where $P_\theta(\theta)P_\theta(\varphi)$, are the probability densities in azimuth and $P_\varphi(\theta)P_\varphi(\varphi)$ represent respectively the functions of angular densities in evaluation in the directions θ and φ. θ is the elevation angle and φ represents the azimuth angle.

In order to evaluate the performance of antenna systems in different propagation channels, different measurements of the distribution of the angles of arrival have been performed at a mobile terminal in urban environments as well as in indoor environments [22].

In this work we consider that the ray angle within a cluster $\tau_{k,l}$ will be modeled as a zero mean Laplacian distribution :

$$\begin{cases} P_\theta(\theta) = \hat{\mu}_\theta \exp\left[-\dfrac{\sqrt{2}\left(\theta-\left(\frac{\pi}{2}-\theta_V\right)\right)}{\sigma_V}\right] \\ P_\varphi(\theta) = \hat{\mu}_\varphi \exp\left[-\dfrac{\sqrt{2}\left(\theta-\left(\frac{\pi}{2}-\theta_H\right)\right)}{\sigma_H}\right] \\ P_\theta(\varphi) = 1 \\ P_\varphi(\varphi) = 1 \end{cases} \quad (11)$$

We consider the arrival azimuth of the k^{th} radius in the l^{th}cluster is given by $\varphi_l + \theta_{k,l}$, where φ_l represent the arrival azimuth in the l^{th} cluster. Thus, the obtained impulse response can be represented as follow:

$$\begin{aligned} h(x_0, y_0, \tau) = \sum_{l=1}^{N_C}\sum_{k=1}^{R_l} \hat{\mu}_{k,1}(t)e^{j\lambda_{k,l}(t)}\delta\Big(\tau - T_l \\ - \frac{1}{c}\left[(x-x_0)\cos(\varphi_l + \theta_{k,l}) + (y-y_0)\sin(\varphi_l + \theta_{k,l})\right]\Big) \quad (12) \end{aligned}$$

The impulse response in equation (12) is obtained by merging in SV channel model, the channel parameters such as loss components, frequency selectivity and spatial characteristics.

4. **Simulation Results**

To design and plan wireless communication systems, it is always useful to simulate the propagation channel. Even though channel models alone do not serve much purpose, they prove to be indispensable tools for the study of wireless communication systems. Once the model is implemented, one can simulate an entire THz system. It is in this sense that the proposed channel module will be simulated for different parameters. So, to visualize the effect of these parameters, we will start with the multi-path aspect of the proposed module.

Fig. 2 shows the transfer function of the channel THz. Parameters that will be used to validate our model are summarized in table 1.

Table 1: Simulation parameters

Parameter	**Value**
f_{min}	100 GHz
f_{Max}	00 GHz
Υ	50 dB
σ_H	15°
σ_V	15°
θ_H	30°
θ_V	30°
Cross polarization rate XPR	1dB
$PL(f_0, d_0)$	71,2 dB

Figure 2 displays the channel transfer function of the proposed model simulated over the 100 GHz - 1000 GHz band. From figure 2, one can conclude that as the frequency increase the channel become more selective which indicate that the proposed model reflects the loss component associated with THz band. This loss is due either on the distance that separate transmitter from receiver as well as it is due to the absorption coefficient in the channel model. On the other hand, it is clear that the proposed model is multi-path model. Because, we can easily generate multipath component in the channel transfer function. As we can see in figure 2, the channel with one path express only attenuation there is no notches. However, for four paths we can see clearly the present of notches in some frequency. The number of notch is equal to the number of path in each case. That indicate clearly the proposed model is multi-path. In fact, attenuation and multipath phenomena are behind the constructive or destructive interference in a transmission chain. These interferences degrade the performance of transmission chain. So, we should take into account these two phenomena in order to build a reliable transmission chain. To see the effect of other parameters on the channel model, we will plot the transfer function of the proposed model for different value of distance between transmitter and receiver.

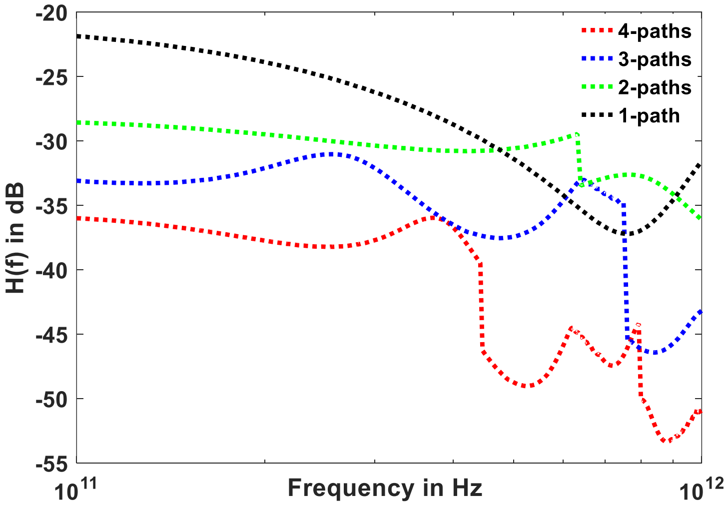

Figure 2 : Channel transfer function of the proposed model from 100GHz to 1000GHz.

In figure 3, we depicted the channel transfer function, limited to the 100 GHz - 1000 GHz band. This simulation is performed with two paths channel model. We can notice from figure 3 that as distance increase between transmitter and receiver, the channel become more selective. Almost, there is no change in the position of notches, but notches become deeper. Thus, as the distance between transmitter and the receiver increase the THz will produce inter-symbols interference which will lead to high BER (Bit Error Rate).

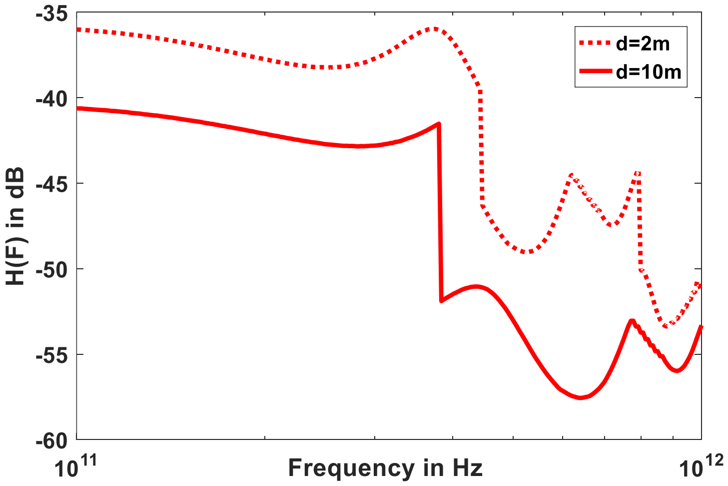

Figure 3 : Channel transfer function versus frequency for d= 2m and d=10 m.

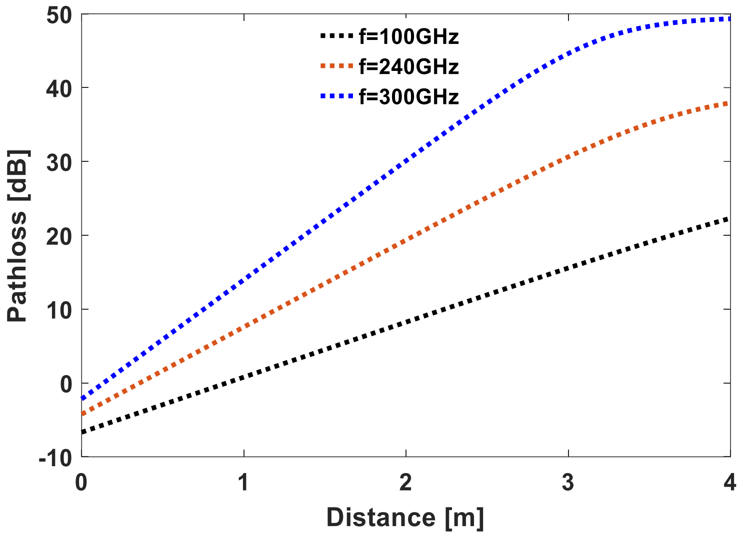

Figure 4: path loss versus distance for different value of frequency: f = 100GHz, 240GHz and 300GHz.

Figure 4 depicts the path loss for the proposed versus distance range from 0 to 4 m, and for different values of frequency (100 GHz, 240 GHz and 300GHz). We show that low values, i.e. d=1m, contribute to a lower rate of attenuation (i.e., $< 0 - 15$ dB). We also perceive that the path loss increases when d increases. similar behaviors can be detected in this figure for d=4 m and d=20m but with diverse dynamicity in the lower THz band as well as in higher band. Indeed, from this figure, we perceive a path loss ranging from 20 dB to 50 dB, while values increase for higher distances.

A complete model must take into account the losses of multipath propagation as shown in figure 2 and figure 3 and the path loss, to provide designers with the impulse and frequency response of the channel, as well as their variations over time for variant channels. This means that the study of path loss is necessary. In the case of a multipath environment such as the case of the THz channel, the path loss no longer follows the Friis free space propagation loss formula. Indeed, for multipath propagation, the power of the received signal is the sum of the power contained in each path. So path loss modeling must take into account multipath and channel configurations (NLOS and LOS). Figure 5 depicts the total path loss versus frequency by taking into account the effect of distance on losses. This figure proves that as the distance between transmitter and receiver increase the loss gradually. As can be seeing in figure 5, losses depend on the distance between transmitter and receiver. Because moving the receiver away from transmitter will affect the propagation channel, so that the channel become more selective especially in some frequency. Because losses depend on frequency too. This dependence on frequency and the distance between transmitter and receiver creates high losses especially at some distance. This phenomenon has been created by the proposed channel model. Thus, it is necessary to take into account this bands when designing a THz system. Account has also been taken of spreading loss and absorption loss which take into account the fact that for the same channel the loss of propagation is not necessarily the same. Therefore, the high losses in THz bands due to the channel, oxygen attenuation and high absorption of materials must to be composite in order to create a reliable transmission chain. To do that, we had to allow high EIRP (Equivalent Isotropic Radiated Power).

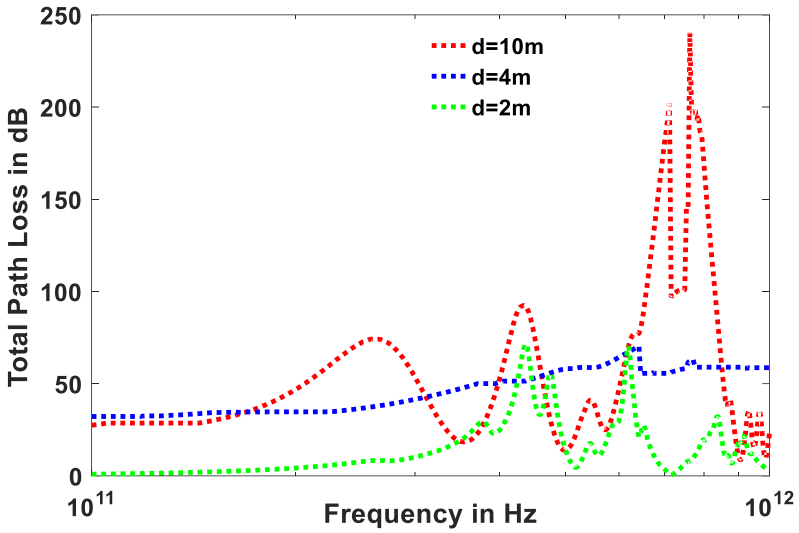

Figure 5: Total path loss versus frequency for d= 2m, 4m and 10m.

In fact, it is possible in THz environments that the propagation losses of the channel evolve because of a rupture of the direct path for example induced by an obstacle or because of absorption loss which characterize the THz environments. These propagation losses degrade the performance of a transmission chain. Thus, the use of directional antennas can be a good option to compensate for propagation losses. The simulations result carried out in this work in this work are in good agreement with results obtained in [23]. Also, it has been demonstrated in above that the proposed model creates transmission bands over which the losses are higher. This assumption has been also demonstrated in [24]. Thus, our model is validating through simulation and by compared our result to those found in [23, 24]. Consequently, the proposed model can be used efficiently to simulate an entire system including transmitters and receivers based on THz technology.

5. Conclusion

This paper presents a mathematical model for THz channel. Based on the ideal case of free space propagation, atmospheric losses and multipath mobile radio channels, we have proposed a propagation channel model that can characterize the THz channel. Losses by propagation and those caused by multi-paths are introduced in the proposed model. The notion of frequency and time selectivity is also presented for multipath channels. These concepts are indispensable for precisely studying the THz channel. To complete the proposed model, it will be possible to implement this model in the communication chain to simulate an entire system including transmitters and receivers.

Data Availability All the data generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflict of Interest The authors declare that they have no conflict of interest.

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