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Investigation of Radio Channel Characterization in Terahertz Range

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To determine the performance of a wireless system, channel characterization must be carried out. In fact, in a wireless system, the propagation of an electromagnetic wave in space is of particular importance. For this reason, it is necessary to study the correctness of this channel before starting to work on it and implementing it in a communication system. It is therefore essential to have knowledge of the mechanisms involved in the propagation channel and of its interactions with the environment in order to be able to predict the chances and conditions for establishing a radio link between a transmitter and a receiver. In this work, we propose some strategies to model the transmission channel in the THz band. Indeed, before we can evaluate a transition system over wireless system, we have to model the propagation channel. First, we present the main tools allowing the modelling of the channel in the THz frequency range, which is considered a key new technology to meet the growing demand for higher speed wireless communications, as well as its impact on radio systems. In this paper, we propose a channel model for a wireless system working in the THz band. Besides, we propose some strategies to model the entire system as well as the propagation channel. We also simulate the proposed channel model. The simulation results show that the proposed system can be considered as an example for evaluating the performance of a communication chain based on a wireless system in the THz bands.

Keywords: Terahertz, Radio channel, Modulation, Impulse response, Spencer's model, LOS, NLOS.

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1. INTRODUCTION

In a world where communication requires faster and faster data transmission, researchers are working on the implementation of techniques and systems capable of transmit high bit rates. In order to achieve and transmit this broadband, it is necessary to increase the frequency that carries the information. For this, scientists are interested in the terahertz (THz) domain which, thanks to its high frequencies between 0.1 THz and 30 THz, provides the ability to increase the throughput. Indeed, the transmission of bit rates of the order of Tbits / s is potentially possible with THz waves, which is advantageous for an application in communication [1]. Since the THz beam is more diffracting [2] and less attenuated by dry and non-metallic objects than infrared, it is of interest for wireless communication indoors. However, the big difficulty is on the one hand to manufacture compact sources, powerful, and inexpensive, and on the other hand THz-sensitive, integrable and robust detectors. The current challenge in the field of telecommunications is to ensure an increase in transmission rates. For this, several techniques are considered, including the rise in frequency towards the millimeter wave spectrum (Terahertz frequency bands). This approach is the basis of this contribution which presents the results of the characterization and statistical modeling of the THz propagation channel [3-7]. A radioelectric transmission system makes it possible to transform an electrical signal emitted $x(t)$ into an electrical signal received $y(t)$ by means of electromagnetic waves OEM. The propagation channel is the transmission medium that carries the electromagnetic waves during their propagation. Generally, this propagation medium has an influence on the electromagnetic wave emitted and will depend on the presence or absence of obstacles in this environment. So, to model the THz channel many parameters must be taking into account in order to drop a valuable model for this environment. In alternative transmission systems with orthogonal frequency division multiplexing (OFDM) [8-11], equalizers are used in the frequency domain based on the use of the fast Fourier transform (FFT), which, with the same error probability, have less complexity. But this method has two significant drawbacks: high signal crest factor and high sensitivity to carrier frequency deviation. This leads to a decrease in the efficiency of power amplifiers and an increase in the complexity and cost of radio equipment in general. Wireless communication in a difficult environment such as an industrial environment requires in-depth study of the propagation channel in order to be able to predict the quality and reliability of radio links. Communication in the THz band will alleviate the spectrum scarcity and capacity limitations of current wireless systems and enable new applications in both classical networking domains as well as new nanoscale communication paradigms.

The study of propagation channel in industrial environment will make it possible to propose strategies of emission/reception of data that makes the exchange of information as reliable as possible. Many researchers have carried out works on the modelling of the THz channel. In [12], authors proposed MB-OOK transceiver design for terahertz bands. Elghzaoui et al. has proposed in [13] multiband on-off keying pulse modulation with noncoherent receiver for THz wireless communication system. In order to propose a reliable model of wireless communication for the smart factory, we will

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study the characteristics of the propagation channel. We will present the different models of propagation channels in an industrial environment taking into account the presence of additive noise. This will then make it possible to propose a robust communication architecture which is the subject of this work.

2. CHANNEL CHARACTERIZATION

During the period of normal propagation in the atmosphere, the waves follow a single path from the transmitting antenna to the receiving antenna. However, it has been known since the 40 s that line-of-sight propagation at frequencies above 1 GHz is sometimes accompanied by rapid and very deep fainting (up to several tens of decibels) that can be interpreted by the presence of several simultaneous propagation paths of the waves between transmitter and receiver. In a multipath situation, the superposition on the receiving antenna of several signals of the same frequency but delayed and out of phase with respect to each other and of different amplitudes, results in an interference phenomenon. Therefore, the resulting signal is accompanied by selective frequency attenuations, that is, not all frequencies of the transmitted band are affected in the same way, hence the name selective fading given to this type of phenomenon. These attenuations can reach several tens of dB and can vary very quickly.

2.1 The Effects of Multiple Trajectories on Communication and Countermeasures

Selective attenuations due to multipath propagation are the most important source of disturbance for high-speed visible radio links at frequencies below 12 GHz. A first degradation is due to the decrease in the received signal power, which is equivalent to an increase in thermal noise. But the essential problem posed by multipaths, as soon as the useful bandwidth exceeds about 10 MHz, is due to the selective nature of the phenomenon. The resulting effect naturally depends on the type of modulation used: intermodulation in the case of analog links in FM (frequency modulation), inter-symbols interference in the case of digital links.

The effect is even more pronounced as the useful bandwidth is large: it therefore particularly affects high-speed digital links, which use a few tens of MHz. From the general characteristics of the phenomenon, one can get an idea of the remedies to be brought. The interference field structure in the vicinity of the receiver leads to the use of diversity methods.

Frequency diversity: where back-up channels are used to transmit the same information. This solution requires only an antenna for reception but is very expensive from the point of view of using the frequency spectrum.

Diversity of space: where two antennas are used for reception, which are a few hundred wavelengths apart vertically. Since the weakening's have a very variable structure over time and in space, the two receptors are very rarely affected in the same way. It is possible to envisage recovering the least disturbed of the two signals, or to carry out a more or less elaborate combination.

2.2 Spatio-Temporal Modeling of the Channel Impulse Response

The studies proposing propagation models are clearly less numerous than those presenting channel characterization results. Some of these studies focus on specific applications, such as inter-vehicle communications [14]. Among those addressing the indoor channel, [15] considers a deterministic model including a statistical consideration of the roughness of reflective surfaces. [16] proposes a model based on a Finite Impulse Response (FIR) filter structure. The model described in [17] is derived from the now classic model of Saleh and Valenzuela [18]. Besides, many ray tracing models are also available in the literature [18]. In the majority of these models, the taking into account of the temporal variations of the channel is always set aside. Occasionally, this choice is justified by the fact that the temporal variations of the channel would be negligible because they would be slow compared to the durations of the symbols envisaged for these transmissions [19]. We saw in the previous chapter that this was not the case. The few models taking into account the influence of human activity use ray tracing techniques [20]. Likewise, except for the ray-tracing models, the angular dimension is absent from the models offered in the millimeter band. The few models taking into account the influence of human activity use ray tracing techniques [20]. Likewise, except for the ray-tracing models, the angular dimension is absent from the models offered in the millimeter band. The few models taking into account the influence of human activity use ray tracing techniques. Likewise, except for the ray-tracing models, the angular dimension is absent from the models offered in the millimeter band.

The spatio-temporal characterization of the channel is justified by several geometric or statistical type models. Consequently, a spatio-temporal modelling of the channel is therefore possible including the angular dimension as well. The models applying to indoor environments are relatively few. Some models are sometimes complex, and it is tricky to configure them correctly to allow easy adaptation to situations other than those for which they were developed (other frequency range for example). Zwick's model is an example of a complete indoor model that is difficult to configure. Among the indoor models, that of Spencer was chosen for its simplicity of adaptation. This model is also based on a model now widely recognized in the field, that of Saleh and Valenzuela [18].

We first present Spencer's model, then the adaptation we made of it for the Terahertz channel in 5G.

Spencer's model was initially parameterized by measurements at 7 GHz. It is based on the observation of a double group phenomenon (clustering the Anglo-Saxon publications): the paths arrive in groups both in the domain of delays (as in the model of Saleh and Valenzuela) and in the angular domain. Spencer assumes that the distributions of delays and angles of arrival are independent of each other (which he then verifies from the measurements).

$$h(t)=\sum_{l=0}^{\infty}\sum_{k=0}^{\infty}\beta_{lk}e^{j\phi_{lk}}\delta(t-T_l-\tau_{lk}), \quad (1)$$

where the sum over l represents the groups of paths, and the sum over *k* the paths within each group. The phase term is statistically independent of the other terms, and Φ_{lk} is modeled by a uniform distribution on $[0, 2\pi[$.

The average power of the paths follows a double exponential decrease according to the delays of the groups and according to the delays of the paths.

$$\overline{\beta_{lk}^2} = \overline{\beta_{00}^2} e^{-\frac{T_l}{\Gamma}} e^{\frac{\eta_k}{\gamma}}, \tag{2}$$

where $\overline{\beta_{00}^2}$is the average power of the first path of the first group (defined from the distance $T_X - R_X$), Γ and γ are the time constants for power attenuation of groups and paths, respectively.

The amplitude β_{lk} are assumed to undergo Rayleigh fading. The number of path groups as well as the number of paths per group each follow a Poisson process. The time difference between two consecutive groups, as well as the time difference between two consecutive paths within a group therefore follow a decreasing exponential law.

The conditional probability density of group delays is defined by:

$$\mathrm{P}(T_l/T_{l-1}) = \begin{cases} e^{\Lambda(T_l - T_{l-1})} t \in \mathbb{N}^* & et \quad T_l \geq T_{l-1} \\ 0 & else \end{cases} \tag{3}$$

where T_l is the delay of group l and Λ is the average group arrival rate (average number of groups per unit time) of the Poisson process.

The conditional probability density of path delays within a group is defined by:

$$p\big(\tau_{lk}/\tau_{l(k-1)}\big) = \begin{cases} e^{\lambda(\tau_{lk} - \tau_{l-1})} & k \in \mathbb{N}^* \quad and \quad T_{lk} \geq T_{l(k-1)} \\ 0 & else \end{cases} \tag{4}$$

where τ_{lk} is the trip delay belonging to the group L (delay relative to the first journey of the group), and λ is the average trip arrival rate (average number of trips per unit time) of the Poisson process.

Spencer completes the temporal model of Saleh and Valenzuela by proposing a representation of the IR (impulse response) similar in the angular domain:

$$h(\theta)=\textstyle\sum_{l=0}^{\infty} \sum_{k=0}^{\infty} \beta_{lk} \delta(\theta - \Theta_l - \omega_{lk}), \tag{5}$$

where θ_l is the mean angle of arrival of group l and ωlk is the angle of the path k within the group L.

The amplitudes β_{lk} are the same as before, as defined in equation (2). The mean angles of arrival of the groups follow a uniform distribution over $[0.2\pi[$.

and the angles of arrival associated with each path follow a Laplacian distribution (modulo 2π) standard deviation σ centered on the average angle of the group to which the trip is associated:

$$p(\omega) = \frac{1}{\sqrt{2\sigma}} e^{\frac{-\sqrt{2}|\omega - \Theta_l|)}{\sigma}}. \tag{6}$$

The first stage for the modeling consists in extracting the characteristics of the paths from the measured impulse responses. These characteristics are the following: time of arrival, angle of arrival and power. The precision of this extraction is limited by the resolution of the measurement late by the temporal resolution (2.3 ns for the measurements), in angle by the angular resolution (6 for measurements). The so-called "high resolution" techniques can improve these resolutions and thus increase the precision of the modeling. However, we did not resort to these techniques mainly for reasons of time. The use of a "high resolution" algorithm requires particular attention to the conditions for acquiring measurements (precise knowledge of the radiation patterns radio THz).

The path detection algorithm that has been developed is based on a search for the significant local maxima of the angle-delay power profiles obtained by the measurements carried out during the campaigns n°2, 3 and 4. Not all local maxima are systematically considered paths. To be validated as a path, a criterion on the gradient is defined as follows.

That is $\bar{g}(t, \theta)$ the gradient at the point (t, θ):

$$\begin{aligned} \vec{g}(t,\theta) &= \tfrac{\partial p(t,\theta)}{\partial t} \vec{\imath}_t + \tfrac{\partial p(t,\theta)}{\partial \theta} \vec{\imath}_\theta, \\ \overrightarrow{g}(t,\theta) &= g_t(t,\theta) \vec{\imath}_t + g_\theta(t,\theta) \vec{\imath}_\theta. \end{aligned} \tag{7}$$

The components of the gradient on the axes delays and angles, $g_t(t, \theta)$ and $g_\theta(t, \theta)$, in the vicinity of the maximum must be greater than an empirically determined threshold for the maximum to be validated as being a path, this which is formulated as follows:

$$\begin{cases} |g_t(t,\theta)| > \delta t_e & t \in \{t_0 - \varepsilon, t_0 + \varepsilon\} & \varepsilon > 0, \\ |g_\theta\, (t,\theta)| > \delta \theta_e & \theta \in \{\theta_0 - \varepsilon, \theta_0 + \varepsilon\} & \varepsilon > 0, \end{cases} \tag{8}$$

where t_0 and θ_0 are the coordinates of the local maximum. The purpose of this criterion is to avoid, or very strongly limit, false detections.

2.3 Arrival Angles of Groups and Journeys

In Spencer's model, the angles of arrival of the groups of paths are uniformly distributed over $[0, 2\pi[$, while those of the paths within the groups are distributed according to a Laplace distribution (considered modulo 2π). The angle of arrival of a group of paths is the average of the angles of arrival of the paths in the group. The angles of arrival of the paths are then related to the angle of arrival of their group.

3. SIMULATION RESULTS

In this section, we will have carried out some simulation to concretize the theatrical part discussed above. Before talking about the proposed channel model, we will give the water vapor density in THz bands. We will take this effect when we trying to model the THz channel. In Fig. 1, we depict the atmospheric attenuation due to water vapor. It can be observed from this figure that the water vapor affects the attenuation of atmosphere when frequency increase especially in some band at the THz band from 30 GHz to 1 THz.

Fig. 2 presents the impulse response of the proposed channel. It can be observed from this figure that the proposed model is multipath model one presents also losses at some frequency which indicate that our model reflects clearly the nature of the THz channel. This model present severe attenuation at some frequencies like for 570 GHz. This figure gives information about the channel losses. Because as the attenuation in the channel becomes tighter, the loss becomes higher. The loss associated with the figure is due to the proposed model based on water attenuation.

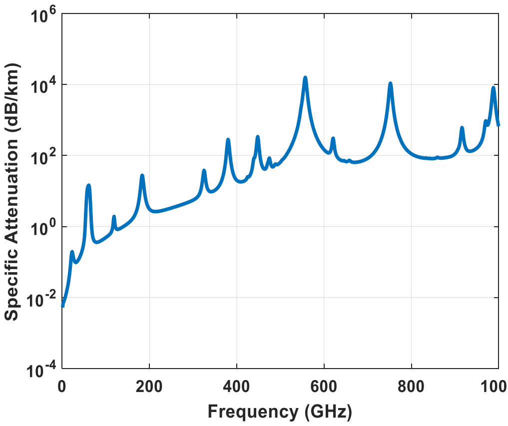

Fig. 1 – Atmospheric attenuation of water vapor

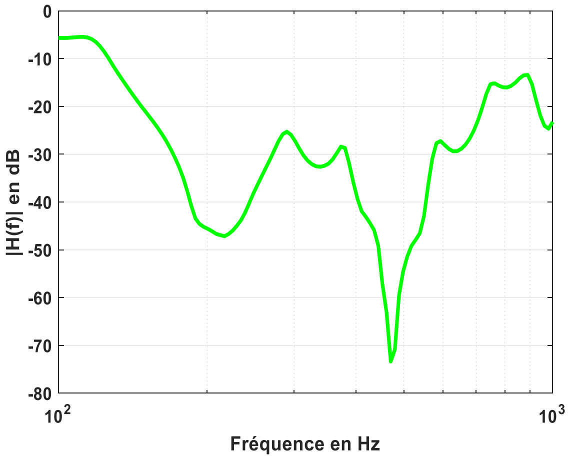

Fig. 2 – Transfer function of THz channel

In Fig. 3, we depict the RMS value for the proposed channel. This parameter plays a crucial role in transmission chain. Because if the channel RMS is larger than the symbol period the performance of the communication system will be worst. So, generally we look for a channel where its RMS is narrow.

The statistics of the groups and the journeys being known, it is then possible to simulate angle-delay power profiles in reception. The input parameters of the algorithm are: the simulated situation (LOS or NLOS), the distance $T_X - R_X$ and a threshold for the underpower simulated routes. Knowing the distance $T_X - R_X$ determines the power of the direct path (the parameter $\overline{\beta_{00}^2}$ of the model), as well as its delay. This delay serves as a reference: all the simulated delays are added to this reference delay.

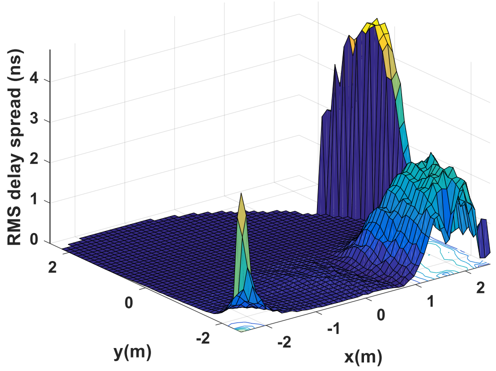

Fig. 3 – RMS of the proposed channel

For the simulation of a situation LOS, the first path of the first simulated group must be the direct route. The simulated delay for this first group is therefore fixed at 0 s. For the simulation of an NLOS situation, the direct path not existing, the simulated delay for the first group is nonzero. It is therefore drawn randomly according to the law governing the delays of groups.

The angles of arrival and the delays of the groups are then determined. Knowing the delays groups, their power is calculated (equation (2)). Then, for each group, the angles and times of arrival of the groups' paths are simulated, as well as their power. The minimum received power threshold passed as a parameter of the model makes it possible to limit the spreading in delays.

All simulated paths with power below the threshold are deleted.

4. CONCLUSIONS

Our contribution presented the channel modelling for THz channel. This modelling includes three axes: modelling of the attenuation according to the distance $T_X - R_X$, modelling of temporal variations in attenuation caused by human activity, and spatio-temporal modelling of impulse responses. Modelling the attenuation as a function of the distance T_X-R_X is based on the free space power loss equation. Coefficients are added to incorporate small-scale variations and the visibility situation. The modelling of the temporal variations of the attenuation is based on an analysis of the statistics of the obstructions caused by human activity.

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Дослідження характеристик радіоканалу в терагерцовому діапазоні

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Щоб визначити продуктивність бездротової системи, необхідно провести характеристику каналу. Насправді, в бездротовій системі поширення електромагнітної хвилі у просторі має особливе значення. З цієї причини необхідно вивчити правильність цього каналу перед початком роботи над ним і впровадженням його в систему зв'язку. Тому важливо знати механізми, які беруть участь у каналі передачі та його взаємодії з навколишнім середовищем, щоб мати можливість передбачити шанси та умови встановлення радіозв'язку між передавачем і приймачем. У роботі ми пропонуємо деякі стратегії моделювання каналу передачі в ТГц діапазоні. Дійсно, перш ніж ми зможемо оцінити систему переходу через бездротову систему, ми повинні змоделювати канал передачі. По-перше, ми представляємо основні інструменти, що дозволяють моделювати канал в ТГц частотному діапазоні, який вважається ключовою новою технологією для задоволення зростаючого попиту на високошвидкісний бездротовий зв'язок, а також його вплив на радіосистеми. У роботі ми пропонуємо модель каналу для бездротової системи, що працює в ТГц діапазоні. Крім того, ми пропонуємо деякі стратегії моделювання всієї системи, а також каналу передачі. Ми також моделюємо запропоновану модель каналу. Результати моделювання показують, що запропоновану систему можна розглядати як приклад для оцінки продуктивності ланцюга зв'язку на основі бездротової системи в ТГц діапазоні.

Ключові слова: Терагерцовий, Радіоканал, Модуляція, Імпульсний відгук, Модель Спенсера, LOS, NLOS.