CHANNEL MODELING FOR CLOUDY WIRELESS NETWORK IN TERAHERTZ BAND

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ABSTRACT

Uunique electrical, mechanical and optical properties makes grapheme an important semiconductor substitute in wide range of application. In this context, graphene antennas are envisioned to enable ultra-high-speed wireless communication in short transmission ranges, due to both their reduced size and their radiation frequency in the terahertz band. Despite its high potential bandwidth, the terahertz band presents several phenomena which may impair the communication and reduce the achievable data rate. This two fold nature of terahertz frequency band can be efficiently analyzed by considering the total path loss and the molecular absorption noise that a wave in the Terahertz Band suffers when propagating over very short distances.

Index Terms— Terahertz, Molecular absorption, Graphene antennas, Graphene-enabled Wireless Communications

I. INTRODUCTION

The development in nanotechnology is enabling to scale devices to a very small size ranging from one to a few hundred nanometers. At this scale, a nanomachine is considered as the most basic functional unit which is only able to perform very simple tasks. Nanocommunication [1], i.e., the transmission of information among nanomachines, will expand the potential applications of individual devices both in terms of complexity and range of operation. So the new advanced applications of nanotechnology in the field of biomedical, military and environmental fields is possible with the help of nanonetworks.

A novel paradigm has recently emerged to implement nanonetworks: Graphene-enabled Wireless Communications (GWC) [2], whose key components are graphene antennas [3]. Graphene [4] , which is just a different atomic orientation of carbon exhibits novel plasmonic properties due to its internal structure, which allow a graphene antenna of a size in the order of 1 μm to radiate electromagnetic waves in the terahertz band (0.1–10 THz) [3], [5].

In this paper, focusing on transmission distances from one centimeter to several meters we designed a communication channel in the terahertz frequency band, considering water vapours present in environment. Based on a recent channel model for short-range wireless communications in the terahertz band [6], we study the impact of molecular absorption on the performance of GWC. In particular, we try to extract the exact bandwidth of operation in terahertz band without any information loss ao simply to extract bandwidth for efficient use of terahertz band. A sample scenario where this study may be useful is that of Graphene Wireless Networks-on-Chip (GWNoC) [7], a novel approach that considers GWC to share information among the cores in a multiprocessor.

In order to determine the frequency band of operation of future graphene-based EM nano-transceivers, it is necessary to characterize the radiation properties of this nanomaterial.
Up to date, several work has been done both from the RF and the optical perspectives. The main difference between the two trends relies on the interpretation of the radiation in terms of high frequency waves or low energy photons. Despite the different origin of the two approaches, they both coincide in the Terahertz Band (0.1-10.0 THz) as the frequency range of operation for the prospect EM nano-transceivers.

In this paper, we focus on EM communications among nano-devices and develop a physical channel model for wireless communication in the Terahertz Band (0.1-10.0 THz). This model allows us to compute the signal path loss, the molecular absorption noise of EM nanonetworks considering environmental conditions. Here we summarize the main contributions of our work as follows:

- ·A channel model for EM nanocommunications in the Terahertz Band by revisiting the concept of molecular absorption in moisture weather and formulations for the total path loss and molecular absorption noise for the same is modeled.

The rest of this paper is organized as follows. In Sec. II, we develop a new channel model for Terahertz communications by using radiative transfer theory. Terahertz channel and different attenuation patterns are calculated in Sec. III. And Sec. IV represents references followed.

II. PROPOSED PROPAGATION MODEL

Graphene-based EM nano-transceivers will operate in the Terahertz Band, the frequency range in the EM spectrum that spans the frequencies between 100 GHz and 10 THz. While the frequency regions immediately below and above this band (the microwaves and the far infrared, respectively) have been extensively investigated, this is still one of the least-explored zones of the EM spectrum.

In the following, the concept of molecular absorption is reviewed and radioactive transfer theory is used to compute the total path loss that a signal suffers when traveling distances in the order of several tens of millimeters or up to a

few meters at most. In addition, the effect of molecular absorption
on the total system noise is investigated and modeled. The proposed model can take into account the contribution from different types and different concentrations of molecules. As a result, this model can be easily tailored to different scenarios and applications of nanonetworks just by determining the composition of the medium.

Molecular Absorption

Several molecules present in a standard medium are excited by EM waves at specific frequencies within the Terahertz Band. An excited molecule internally vibrates, i.e., its atoms show periodic motion while the molecule as a whole has constant translational and rotational motions. As a result of this vibration, part of the energy of the propagating wave
is converted into kinetic energy or, from the communication.

In our analysis, we use radiative transfer theory [7] and the information provided by the HITRAN database to compute the attenuation that a wave traveling distances up to a few meters suffers due to molecular absorption by water molecules. To calculate attenuation caused by a particular molecule, we first compute the fraction of incident EM radiation at a given frequency that is able to pass through the medium. This parameter is defined as the transmittance of a medium, τ, and is obtained by using the Beer-Lambert Law as:

$$\tau(f,d) = \frac{P_0}{P_i} = e^{-k(f)d} \dots\dots\dots\dots\dots\dots (1)$$

where f is the frequency of the EM wave, d stands for the total path length, Pi and $P0$ are the incident and radiated powers and k is the medium absorption coefficient. This last parameter depends on the composition of the medium, i.e., the particular mixture of molecules found along the channel, for our case its water vapor and it is defined as:

$$k(f) = \sum_{i,H2O} k^{i,H2O}(f) \dots\dots\dots\dots.. (2)$$

where f is the frequency of the EM wave and $k^{i,\mathrm{H2O}}$ stands for the H2O absorption coefficient for the isotopologue i of H2O.
The absorption coefficient of the isotopologue i of H2O, $k^{i,\mathrm{H2O}}$, in m−1, for a molecular volumetric density, $Q^{i,\mathrm{H2O}}$, in molecules/m3 at pressure p and temperature T can be written as:

$$k^{i,H2O}(f) = \frac{p}{p_0}\frac{T_{STP}}{T} Q^{i,H2O}\sigma^{i,H2O}(f) \dots\dots\dots\dots\dots\dots. (3)$$

where $p0$ and $TSTP$ are the Standard-Pressure-Temperature values and $\sigma^{i,\mathrm{H2O}}$ is the absorption cross section for the isotopologue i of H2O in m2/molecule. Simply stated, the total absorption depends on the number of molecules of H2O that are found along the path.

For H2O, the total number of molecules per volume unit, $Q^{i,\mathrm{H2O}}$, of the isotopologue i of H2O in molecules/m3, at pressure p and temperature T , is obtained
from the Ideal Gas Law as:

$$Q^{i,H2O} = \frac{n}{V} q^{i,H2O} N_A = \frac{p}{RT} q^{i,H2O} N_A \dots\dots\dots\dots\dots (4)$$

where n is the total number of moles of the gas mixture that is being considered, V stands for the volume, $q^{i,\mathrm{H2O}}$ is the mixing ratio for the isotopologue i of H2O, N_A stands for the Avogadro constant and R is the gas constant. In the HITRAN database, the contribution of each isotopologue has been scaled according to its natural abundance in the medium. Therefore, the mixing ratio of the H2O, should be used for all the isotopologues of H2O, instead of the individual mixing ratios $q^{i,\mathrm{H2O}}$.

The absorption cross section $\sigma^{i,\mathrm{H2O}}$ in (3) can be further decomposed in terms of the line intensity $S^{i,\mathrm{H2O}}$ for the absorption of the isotopologue i of H2O and the spectral line shape $G^{i,\mathrm{H2O}}$ as:

$$\sigma^{i,H2O}(f) = S^{i,H2O} G^{i,H2O}(f) \dots\dots\dots\dots\dots (5)$$

The line intensity $S^{i,\mathrm{H2O}}$ defines the strength of the absorption by a specific type of molecules and is directly obtained from the HITRAN database. To obtain the line shape, $G^{i,\mathrm{H2O}}$, we first determine the position of the resonant frequency $f^{i,\mathrm{H2O}}{}_c$ for the isotopologue i of H2O. This increases linearly with the pressure p from its zero-pressure position $p0$ as:

$$f_c^{i,H2O} = f_{c0}^{i,H2O} + \delta^{i,H2O}\, p/p_0 \dots\dots\dots\dots\dots (6)$$

where $fi,\mathrm{H2O}$ $c0$ is the zero-pressure position of the resonance and $\delta i,\mathrm{H2O}$ is the linear pressure shift. All these parameters are directly read from the HITRAN database.

The absorption from a particular molecule is not confined to a single frequency, but spread over a range of frequencies. For a system in which the pressure is above 0.1 atm, the spreading is mainly governed by the collisions between molecules of the same gas [7]. The amount of broadening depends on the molecules involved in the collisions and it is usually referred as the Lorentz half-width $\alpha^{i,\mathrm{H2O}}{}_L$. We can obtain this parameter as a function of the air and self-broadened half-widths, $\alpha^{air}{}_0$ and $\alpha^{i,\mathrm{H2O}}{}_0$ respectively, as:

$$\alpha_L^{i,H2O} = \left[(1-q^{i,H2O})\alpha_0^{air} + q^{i,H2O}\alpha_0^{i,H2O}\right]\left(\frac{p}{p_0}\right)\left(\frac{T_0}{T}\right)^{\gamma} \dots\dots\dots\dots (7)$$

where $q^{i,\mathrm{H2O}}$ is the mixing ratio for the isotopologue i of H2O, p is the system pressure, $p0$ refers to the reference pressure, $T0$ is the reference temperature, T refers to the system temperature and γ is the temperature broadening

coefficient. The values of γ, $\alpha^{air}{}_0$ and $\alpha^{i,\,H2O}{}_0$ are obtained directly from the HITRAN database. Therefore, the number of molecules does not only increase the amplitude of the peak of the absorption (5), but also makes the shape of the absorption peaks wider, i.e., the useful transmission windows narrower.

For the frequency band that we are considering (relatively low frequencies when compared to the infrared and the light range in which this is usually applied), we choose the Van Vleck-Weisskopf asymmetric line shape [8] to represent the molecular absorption:

$$F^{i,H2O}(f) = 100c\frac{\alpha_L^{i,H2O}}{\pi}\frac{f}{f_c^{i,H2O}}\left[\frac{1}{\left(f-f_c^{i,H2O}\right)^2+\left(\alpha_L^{i,H2O}\right)^2}+\frac{1}{\left(f+f_c^{i,H2O}\right)^2+\left(\alpha_L^{i,H2O}\right)^2}\right] \dots\dots (8)$$

where f stands for the frequency of the EM wave, c is the speed of light in the vacuum, $\alpha^{i,\mathrm{H2O}}{}_L$ is the Lorentz half-width coefficient for the isotopologue i of H2O and $f^{i,\,\mathrm{H2O}}{}_c$ is the resonant frequency for the isotopologue i of H2O. An additional adjustment to the far ends of the line shape can be done in order to account for the continuum absorption as first proposed in [2]:

$$G^{i,H2O}(f) = \frac{f}{f_c^{i,H2O}}\frac{tanh\left(\frac{hcf}{2K_BT}\right)}{tanh\left(\frac{hcf_c^{i,H2O}}{2K_BT}\right)}F^{i,H2O}(f) \dots\dots (9)$$

where h is the Planck constant, c is the speed of light in the vacuum, kB stands for the Boltzmann constant and T is the system temperature.

With this, we are able to compute the contributions to the total molecular absorption from each isotopologue i of H2O present in the medium.

Finally, the total attenuation that an EM wave of frequency
f suffers due to molecular absorption when traveling a distance d can be obtained from the transmittance of the medium τ given by (1) as:

$$A_{abs}(f,d) = \frac{1}{\tau(f,d)} = e^{k(f)d} \dots\dots (10)$$

Or in dB

$$A_{abs}(f,d)[dB] = k(f)d10log_{10}e \dots\dots (11)$$

PATH LOSS

The total path loss for a traveling EM wave in the Terahertz Band is obtained as the addition in dB of the spreading loss $Aspread$ and the molecular absorption attenuation $Aabs$

$$\mathrm{A(f,d)[dB]} = \mathrm{A_{spread}(f,d)[dB]} + A_{abs}(f,d)[dB] \dots\dots (12)$$

where d is the total path length and f stands for the wave frequency. The spreading loss accounts for the attenuation due to the expansion of a wave as it propagates through the medium, i.e., the free-space loss. This is defined in dB as

$$A_{spread}(f,d)[dB] = 20log\left(\frac{4\pi fd}{c}\right) \dots\dots (13)$$

where d is the total path length, f is the frequency of the EM wave and c stands for the speed of light in the vacuum. Within the Terahertz Band, the spreading loss is considerably large, limiting the maximum transmission range of future nano-devices. While this is a major inconvenience for the classical applications for Terahertz communications envisioned so far, we are proposing the use of this band for nanoscale and microscale communications, in which the transmission distance is small, i.e., in the order of several tens of millimeters.

Molecular Absorption Noise Temperature

Up to this point, it has been considered that the molecules present in the medium only affect the properties of the channel in terms of attenuation. However, molecular absorption also introduces noise [3]. Indeed, the internal vibration of the molecules turns into the emission of EM radiation at the same frequency that the incident waves that provoked this motion.

In our model, we consider this as a noise factor that affects the propagation of EM waves in the Terahertz Band and we provide a way to compute it. The parameter that measures this phenomenon is the emissivity of the channel, □, and it is defined as

$$\in (\mathrm{f,d}) = 1 - \tau(\mathrm{f,d}) \dots\dots (14)$$

where f is the frequency of the EM wave, d stands for the total path length and τ is the transmissivity of the medium given by (1).

The equivalent noise temperature due to molecular absorption $Tmol$ in Kelvin that an omnidirectional antenna detects from the medium is further obtained as:

$$T_{mol}(f,d) = T_0 \in (f,d) \dots\dots (15)$$

where f is the frequency of the EM wave, d stands for the total path length, T0 is the reference temperature and ε refers to the emissivity of the channel given by (1). This type of noise is only present around the frequencies in which the molecular absorption is considerably high. Water vapor is again the main factor altering the Terahertz channel.

III. SIMULATION RESULT AND CONCLUSION

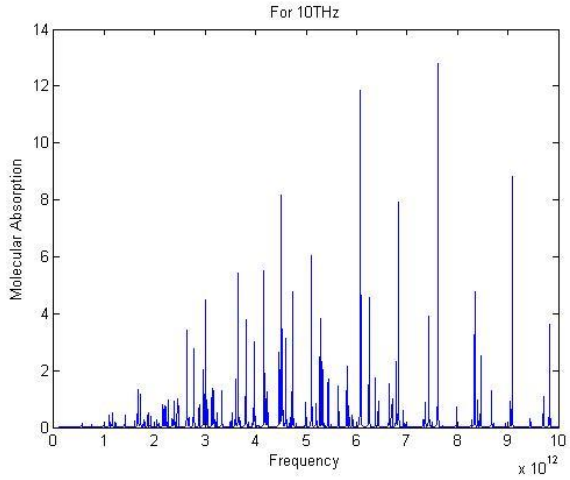

Figure.1 for water molecule i.e.0.01%

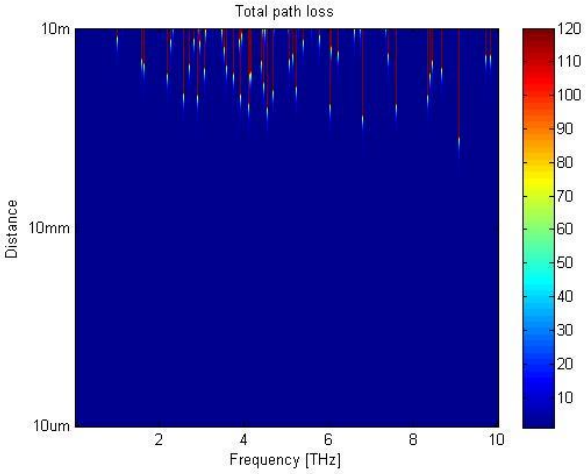

Figure 2. Path loss of signal in water molecule0.01%

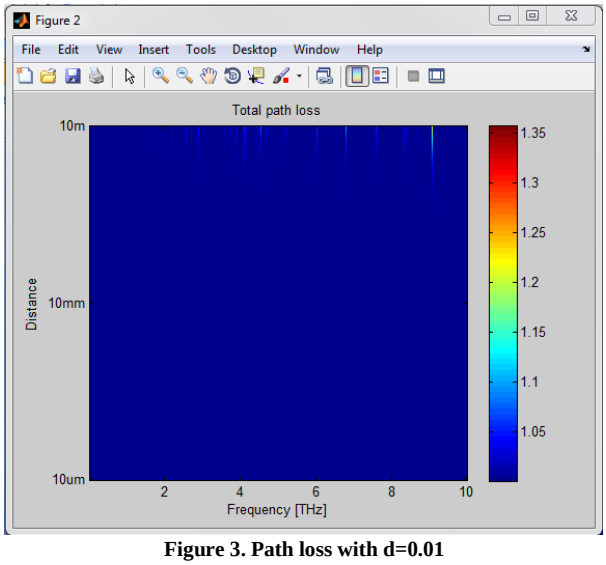

Figure 3. Path loss with d=0.01

In order to illustrate and understand the different properties of the Terahertz Band from the communication perspective, the proposed channel model is evaluated for different H2O compositions, in terms of total path loss and molecular absorption noise.

Fig.1 shows molecular absorption co-efficient for frequency up to 10THz. And it is analyzed that in the frequency band 0~5THz attenuation is low. So this band can be used for efficient terahertz communication.

Fig.2 and Fig.3 shows increase in total path loss when distance d increases from 0.1cm to 0.01cm for water vapor percentage of 0.01%. The total path loss, A, given by (2), depends on the EM wave frequency f, the transmission distance d and the composition of the medium that is being considered.

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