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Tunnel Propagation Modeling for Communication Technology using Principles of Radar Theory

Approach for Calculation of received power in any internal point of a tunnel

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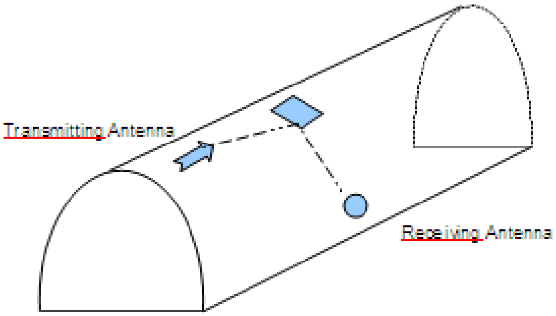
***Abstract*—Wireless communication is in its nature volatile due to rapidly varying propagation conditions between the transmitters and receivers. The propagation conditions inside the tunnels are different from what is experienced in areas outside the tunnels. This paper presents a new method to calculate received power in a defined point inside the tunnel.**

I. Introduction

This approach can be used to simulate radio propagation for every technology like GSM, UMTS, LTE, TETRA, etc… Obviously, the accouracy depends on many factors such as the tunnel surface roughness, size, shape, …[1]

The rapidly changing propagation conditions will affect the quality of the received signal and thus influence the receiver's ability to interpret the conveyed message.



II. Initial Assumptions

A. *Observation*

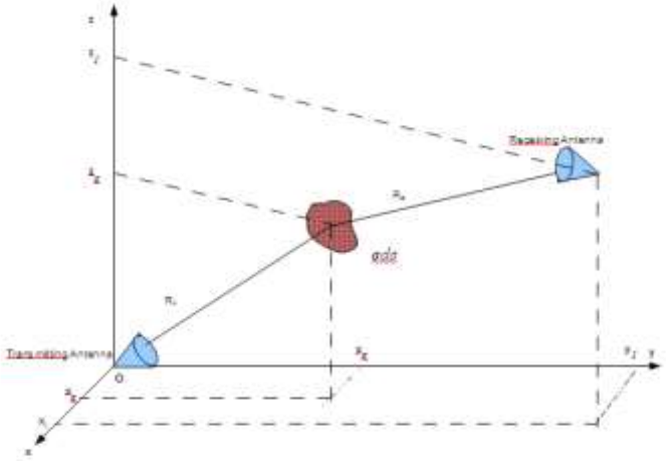
In many articles the models are developed on the basis of statistical averages from propagation measurements.

In this document the idea comes from the observation that the received signal in any point inside the tunnel is given by the sum of each contribute resulting from scattering of every incident EM waves on tunnel surface and directed towards the receiver antenna.

So, we can consider that the infinitesimal element of scattering tunnel surface is

$$\sigma d\sigma$$

This quantity is similar to what, in Radar Theory, is called Radar Cross Section. [2]



B. *Channel Propagation Model*

Now we have to define some variables:

P_T represents the Power Transmitted, measured at the connector of Tx Antenna. This variable doesn't depends on the position of $\sigma d\sigma$.

$G_T(\mathbf{x_\sigma,y_\sigma,z_\sigma})$ is the Gain of Tx Antenna; its value strictly depends on the relative position of $\boldsymbol{\sigma d\sigma}$.

$G_R(\mathbf{x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma})$ is the Gain of Rx Antenna; as for G_T it depends on the relative position of $\boldsymbol{\sigma d\sigma}$ and the position of the Rx Antenna**.**

λ is the wavelength.

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$R_T(\mathbf{x_\sigma,y_\sigma,z_\sigma})$ is the distance of the infinitesimal scattering element from the Tx Antenna, and is dependent on the position of ***σdσ.***

$R_R(\mathbf{x_1\text{-}x_\sigma,y_1\text{-}y_\sigma,z_1\text{-}z_\sigma})$ is the distance of the Rx Antenna from the infinitesimal scattering element, and is dependent on the position of ***σdσ.* [3]**

At this point, we can write the infinitesimal power received at the Rx Antenna connector from scattering of the ***σdσ*** element as:

$$dPR(x_1,y_1,z_1)=\frac{P_TG_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2\sigma\,d\sigma}{(4\pi)^3R_T(x_\sigma,y_\sigma,y_\sigma)R_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_TL_RL_P(x_\sigma,y_\sigma,z_\sigma)} \quad (1)$$

Where L_T, L_R is losses at the transmitter and receiver and doesn't depends on *σdσ*. L_P is losses due to polarization effect and is a function of *σdσ*. [4]

III. Scattered Power Contribute

Assuming the surface *σdσ* is an infinitesimal element of internal tunnel surface, we can write the relation:

$$\sigma d\sigma = (x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma \quad (2)$$

So proceeding with the substitution of (2) in (1) we obtain:

$$dPR(x_1,y_1,z_1)=\frac{P_TG_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_TL_RL_P(x_\sigma,y_\sigma,z_\sigma)} \quad (3)$$

Finally, to calculate the scattered power in (x_1,y_1,z_1) we have:

$$\int dPR(x_1,y_1,z_1)=\iint\frac{P_TG_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_TL_RL_P(x_\sigma,y_\sigma,z_\sigma)} \quad (4)$$

A. *Total Power Received in (x₁,y₁,z₁)*

At this point to calculate the total power at the receiver antenna, we have to sum the direct signal with the scattered component, obtaining:

$$PR_{tot}(x_1,y_1,z_1)=\frac{P_TG_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)\lambda^2}{(4\pi)^2R^2L_TL_RL_P}+\iint\frac{P_TG_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_TL_RL_P(x_\sigma,y_\sigma,z_\sigma)} \quad (5)$$

B. *Final Equation*

- Highlightinng the terms not dependent from x and y, we have:

$$\overline{PR}_{tot}(x_1,y_1,z_1)=\frac{P_TG_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)\lambda^2}{(4\pi)^2R^2L_TL_RL_P}+\frac{P_T\lambda^2}{(4\pi)^3L_TL_R}\iint\frac{G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_P(x_\sigma,y_\sigma,z_\sigma)} \quad (6)$$

simplifying:

$$PR_{tot}(x_1,y_1,z_1)=\frac{P_T\lambda^2}{(4\pi)^2L_TL_R}\left(\frac{G_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)}{R^2L_P}+\iint\frac{G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_P(x_\sigma,y_\sigma,z_\sigma)}\right) \quad (7)$$

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The equation obtained is not really so simple to use, but considering some simplifications such as Omnidirectional Antennas, material that does not change polarization, we are able to estimate the received power in any point of tunnel.

References

[1] V. Ringset, "Tunnel propagation measurement and modeling" SINTEF ICT, pp. 1–10.

[2] M. Jalilvand, Microwave FMCW Radar, Karlshuer Institut fur Technologie, 2014, pp.1–6.

[3] M. I. Skolnik, "Introduction to Radar Systems", McGraw-Hill International Eds., second edition, 1980, pp. 30–54.

[4] R.E.Collin, "Antenna and Radiowave Propagation", McGraw-Hill International Eds.1985, pp. 303-306.

[5] P. Peregrinus, "Reflector Antenna Analysis and Design" Ltd. London, 1980 (IEE publication).

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