Tunnel Propagation Modeling for Communication Technology using Principles of Radar Theory

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

Andrea Piroddi

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.
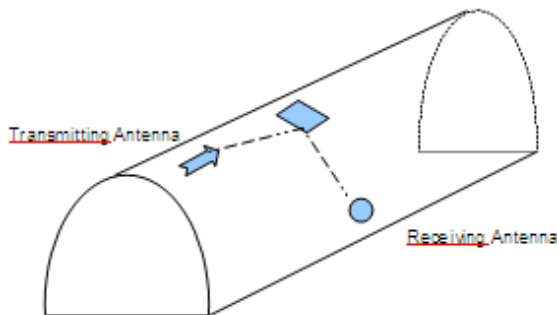
II. Initial Assumptions

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
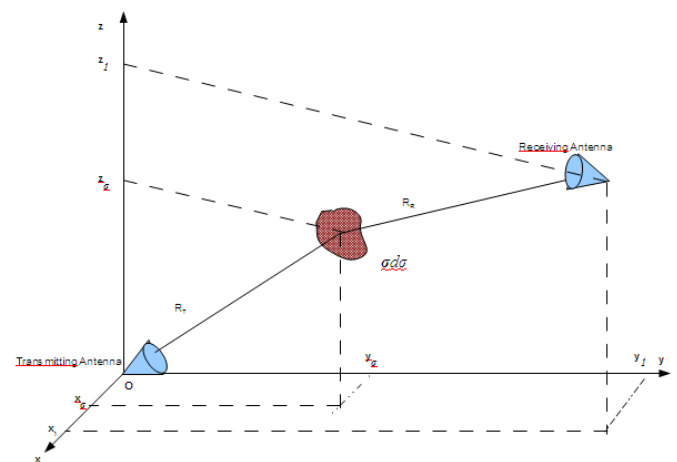
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Andrea Piroddi
Tor Vergata University, Rome Italy

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 $\sigma d\sigma$.

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

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

λ is the wavelength.

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

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

At this point, we can write the infinitesimal power received at the Rx Antenna connector from scattering of the $\boldsymbol{\sigma d\sigma}$ element as:

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

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

III. Scattered Power Contribute

Assuming the surface $\sigma d\sigma$ is an infinitesimal element of internal tunnel surface, we can write the relation:

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

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

$$dPR(x_{1,}y_{1,}z_1) = \frac{P_T G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3 R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_T L_R L_P(x_\sigma,y_\sigma,z_\sigma)} \quad (3)$$

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

$$\int dPR(x_{1,}y_{1,}z_1) = \int\int \frac{P_T G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3 R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_T L_R L_P(x_\sigma,y_\sigma,z_\sigma)} \quad (4)$$

A. Total Power Received in (x_1,y_1,z_1)

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

$$PR_{tot}(x_{1,}y_{1,}z_1) = \frac{P_T G_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)\lambda^2}{(4\pi)^3 R^4 L_T L_R L_P} + \int\int \frac{P_T G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)\lambda^2(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{(4\pi)^3 R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_T L_R L_P(x_\sigma,y_\sigma,z_\sigma)} \quad (5)$$

B. Final Equation

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

$$\overline{PR}_{tot}(x_{1,}y_{1,}z_1) = \frac{P_T G_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)\lambda^2}{(4\pi)^3 R^4 L_T L_R L_P} + \frac{P_T\lambda^2}{(4\pi)^3 L_T L_R}\int\int \frac{G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_P(x_\sigma,y_\sigma,z_\sigma)} \quad (6)$$

simplifying:

$$PR_{tot}(x_{1,}y_{1,}z_1) = \frac{P_T\lambda^2}{(4\pi)^3 L_T L_R}\left(\frac{G_T(x_1,y_1,z_1)G_R(x_1,y_1,z_1)}{R^4 L_P} + \int\int \frac{G_T(x_\sigma,y_\sigma,z_\sigma)G_R(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)(x_\sigma-dx_\sigma)(y_\sigma-dy_\sigma)dx_\sigma dy_\sigma}{R_T^2(x_\sigma,y_\sigma,y_\sigma)R_R^2(x_1-x_\sigma,y_1-y_\sigma,z_1-z_\sigma)L_P(x_\sigma,y_\sigma,z_\sigma)}\right) \quad (7)$$

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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.

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

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

About Author (s):

Since 2013: Associate Member of UACEE. Since 2009: Collaboration as a guest lecturer and consultant for the School of Computer Science at St. Andrew's University, as part of the Energy-efficient sensing in wireless sensor networks using compressed sensing. Since 2008: Consultant for various companies in the ICT services sector with responsibility for the design and development of the infrastructure of Core Network and Services, WiFi / MESH. Since 1997: in Vodafone Italy NV, in the role of Delivery Manager in department of Operations for Central Italy