Modal Theory and MIMO Channels in Tunnels

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The capacity of wireless channels can be considerably increased if the multipath propagation is properly exploited by means of multi-element arrays. This technique is based on Multiple Input - Multiple Output (MIMO) considerations (G.J. Foschini and M.J. Gans, *Wireless Personal Commun.*, **6**, 311-315, 1998). In this paper, we study a special environment by applying MIMO to propagation to tunnels. In a multipath environment, it is often assumed that fades of the various channels follow a Rayleigh distribution and are independently distributed. Inside a tunnel, however, one can expect that, because of the waveguide-like structure, the angular spread of arrival of the rays on a receiving antenna is not as large as in a building, for example. We have performed a detailed analysis to predict the performance of MIMO techniques in such environment.

The channel characteristics can be determined using a propagation model based on ray theory (M. Lienard et al, *IEEE J. on Selected Areas in Comm.*, **21**, 332-339, 2003). However, the interpretation of the results in terms of the channel capacity as a function of the range is rather difficult. Indeed, the efficiency of a MIMO technique strongly depends on the number of modes supported by the structure and on the correlation between both transmitting and receiving array elements. In this presentation, we propose to base the interpretation on a modal approach.

To obtain closed form solutions for the EM field, we consider a straight rectangular tunnel. After discussing the approximation of mode orthogonality, we use ray theory to determine the weight of the hybrid modes excited by a transmitting dipole. We present examples in which we consider a transmitting frequency of 900 MHz and various tunnel sizes. The concept of dominant or active modes is introduced and a parametric study emphasizes the variation of the number of these active modes, depending on the tunnel dimension, on the transverse position of the transmitting antenna, and on the distance between the transmitter and the receiving plane. We generalize this approach to treat the MIMO case. The correlation between modes excited by each element array and the correlation distance between receiving elements are determined to optimize the element spacing. In conclusion, we provide interpretation of the variation of ergodic capacity as a function of range and tunnel sizes.