EVALUATION OF MULTIPLE ANTENNA SYSTEM CAPACITY IN SUBWAY TUNNELS

Narges Noori(1), Homayoon Oraizi(1) and S. Mohammad Razavizadeh(2)

(1)Department of Electrical Engineering
Iran University of Science and Technology
Narmak, 16844 Tehran, Iran
E-mail: {nnoori, h_oraizi}@iust.ac.ir

(2)Department of Electrical & Computer Engineering
University of Waterloo
Waterloo, Ontario, Canada N2L3G1
E-mail: smrazavi@cst.uwaterloo.ca

Abstract: Wireless communication systems that use Multiple Input-Multiple Output (MIMO) architectures can achieve very high spectral efficiencies. Evaluation of the channel capacity for these systems requires an accurate characterization of the radio propagation environment. In this paper, a three dimensional ray tracing method is used to evaluate the channel capacity of MIMO systems in a subway tunnels. This deterministic method is able to tack into account the dependency of the channel capacity on the characteristics of the real propagation environment which is not possible by statistical methods.

1. Introduction

In recent years, discoveries in the information theory have showed that using multiples antennas at both ends of a wireless communication system can give a impressive gains over systems with single antenna [1],[2]. In multiple-input multiple-output (MIMO) systems the channel capacity increases with the number of antennas without increasing the bandwidth or power. With the growing demand for high data rate wireless communication services which suffer from bandwidth and power restrictions, employing MIMO systems has become an attractive technique to overcome these difficulties. Evaluation of the MIMO channel capacity needs to determine channel matrix of the propagation environment. Most of the published works are based on assuming a Rayleigh fading channel and evaluating the statistical average of the channel capacity[1],[2]. Unfortunately, the statistical approaches can not take in to account the characteristics of the propagation environment on the capacity calculation. There are also some other papers that use measurements to estimate the channel capacity in MIMO systems [3]. Another method to determine the channel capacity of MIMO systems is applying the deterministic methods base on the accurate modeling of the propagation environment.

In this paper, we develop a site-specific approach based on ray tracing (RT) method to determine the channel matrix and then the capacity of MIMO systems in a subway tunnels medium. The RT method has been used as an efficient approach to model radio wave propagation inside tunnels [4], [5]. In the following sections, we will explain the proposed method and present some results for different physical configurations and antenna polarizations.

2. Wave propagation modeling in Tunnels

Assume a tunnel of width W and height H where the ambient medium has the relative permittivity of $\varepsilon = \varepsilon_r - j60\sigma\lambda$ as its cross section is shown in Fig. 1. Inside this tunnel, a transmitter antenna is located at

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(x_t, y_t, z_t) while the receiver antenna at (x_r, y_r, z_r) moves horizontally. The received signal can be expressed by RT method as summation of the direct and all reflected waves at the receiver as follow [6]:

$$E = \frac{E_0 e^{-jkr}}{r} + \sum_i \frac{E_0 \Gamma_i e^{-jkr_i}}{r_i} \tag{1}$$

where Γ_i is the product of the reflection coefficient of all tunnel walls for *i*th ray, and r and r_i are the path lengths of the direct and the ith reflected rays. The above process is repeated for each pair of transmit antennas and receive antennas and to determine the channel matrix T for the propagation environment. When the receiver moves along a path, the process of channel matrix determination must be repeated for each receiving point.

3. MIMO channel capacity

In a MIMO system with N_t transmit and N_r receive antennas, the channel capacity in b/s/Hz is defined as follow [1], [2]

$$C = \log_2\left(\det\left[\boldsymbol{I}_{N_r} + \frac{\rho}{N_t}\boldsymbol{HH}^*\right]\right) \tag{2}$$

where **H** is the normalized channel matrix and $\mathbf{H}^*$ is its hermitian and ρ is the average signal to noise ratio (SNR) at each receiver antenna. The maximum capacity is obtained as follow when all the sub-channels have equal gain:

$$C = \min(N_t, N_r)\log_2\left(1 + \frac{\rho}{\min(N_t, N_r)} N_r\right) \tag{3}$$

The normalized channel matrix **H** is obtained by performing the Frobenius norm on **T** as:

$$\boldsymbol{H} = \frac{\boldsymbol{T}}{\sqrt{\dfrac{\sum_{m=1}^{N_r}\sum_{n=1}^{N_t}\left|\boldsymbol{T}_{m,n}\right|^2}{N_t N_r}}} \tag{4}$$

Therefore the channel capacity can be obtained from the normalized channel matrix for each receiver location.

4. Simulation results

We perform our simulations in a subway tunnel 5m high and 6m wide with $\varepsilon_r = 5$ and $\sigma = 0.02$ S/m at the operating frequency of 900MHz. Isotropic antennas are used at the transmitter and receiver arrays. The average SNR at each receiver antenna is assumed to be 20dB.

Figs. 2 and 3 illustrate the channel capacity variation for two 4×4 and 2×2 MIMO systems, respectively, and compare the simulation results with the maximum achievable MIMO channel capacity and single-input single-output (SISO) system capacity. The transmit and receive arrays are horizontally arranged along the *x* axis. The transmitter is fixed at 3.5m above the tunnel floor while the receiver moves along the center line of the tunnel. The distances between transmit antennas are 4λ and between receive antennas are 2λ. It is shown in these figures that the MIMO systems with horizontally polarized antennas give capacity improvement with respect to the MIMO systems with vertically polarized antennas.

In Fig. 4, the channel capacity is shown for two different transmit antennas distances. As it is expected, when the transmit antenna distances are changed from λ to 4λ, the wider antenna spacings results in lower signal correlation and therefore, a considerable channel capacity improvement is achieved.

In order to study the effect of antenna array orientation on the MIMO channel capacity, we arranged the

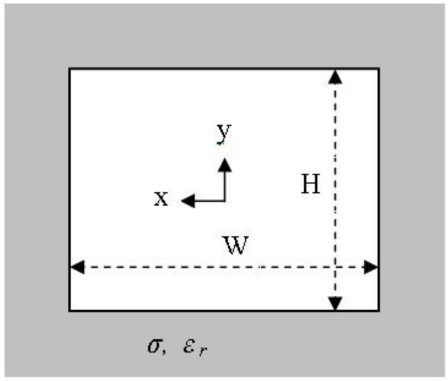

Fig. 1. Cross Section of the tunnel.

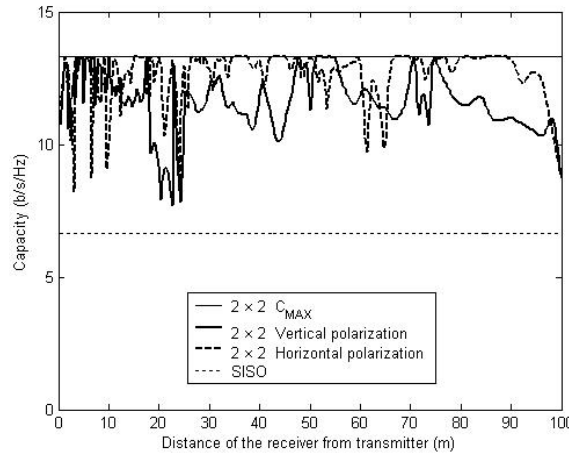

Fig. 3. Comparison of the channel capacity for different polarization for a MIMO system with 2 transmitters and 2 receivers.

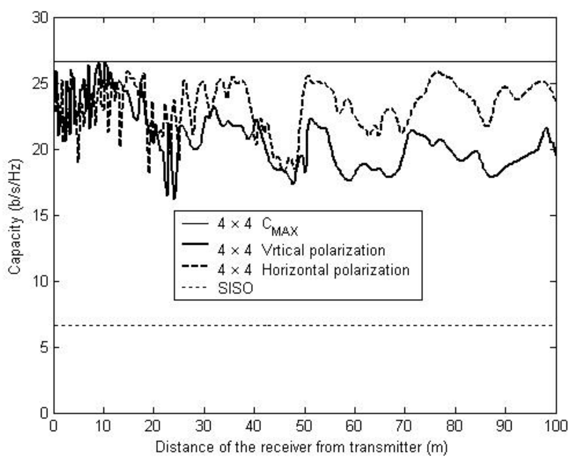

Fig. 2. Comparison of the channel capacity for different polarization for a MIMO system with 4 transmitters and 4 receivers.

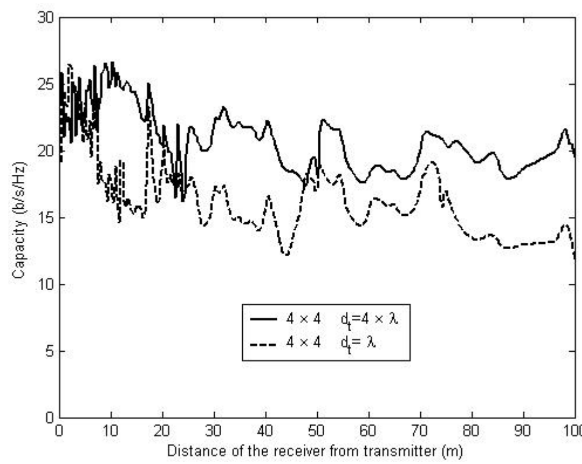

Fig. 4. Comparison of the channel capacity, the distances between transmitter antennas are λ and 4λ .

transmit array vertically along the y axis while the receive array is arrange horizontally along the x axis as before (YX). Channel capacity variation in this case is shown in Fig. 5 and is compared with the case that both of transmit and receive arrays are arranged horizontally along the x axis (XX). It can be seen that XX case shows capacity improvement against YX case.

Fig. 6 shows the variation of the channel capacity with SNR at a distance of 100m from the transmitter for SISO and 2×2 and 4×4 MIMO systems. The considerable increase in the channel capacity can be seen when the number of the antennas is increased.

5. Conclusions

In this paper, an accurate technique based on ray tracing method was proposed to determine the MIMO systems channel capacity in a subway tunnels medium. The simulation results and comparisons were

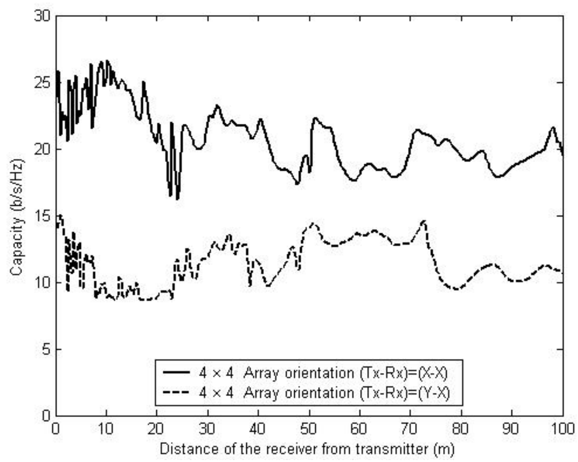

Fig. 5. Comparison of the channel capacity, for two different transmitter array orientations.

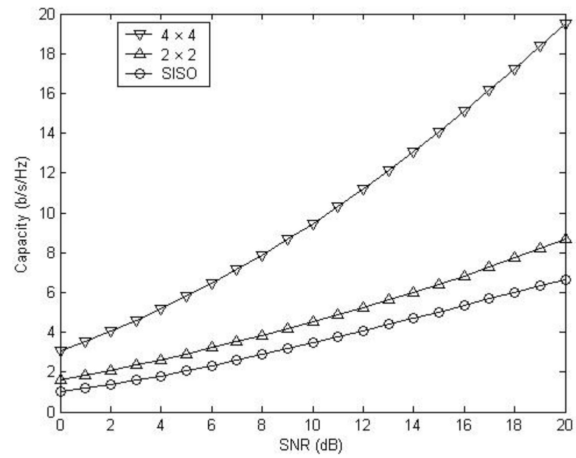

Fig. 6. Comparison of the channel capacity for different SNR values.

presented for different polarizations and antenna configurations. The results showed the dependency of the channel capacity to configuration and polarization of the antennas and also to the characterization of the propagation environment which it is not considered in channel capacity calculation with statistical models.

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