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Improving Channel Capacity by Propagation Prediction Model Using MIMO in Tunnels

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Abstract: *A ray tracing approach with theoretical and experimental results to show the condition in which MIMO techniques allow the erogodic capacity of the channel may be increased. MIMO techniques, based on multiple antennas at both the transmitting and receiving sites, used to analyse the capacity due to multipath propagation to transform the overall channel into numerous independent virtual channels. However, when the link is made in a long tunnel, the number of reflecting objects between, or near the transmitter and the receiver is often quite low. The result shows the capacities of MIMO channel in LOS path are less than non line of sight in indoor tunnels in 1800 MHz band. In addition, due to the large transverse dimension of the tunnel compared to the wave length, the tunnel acts like a lossy oversized wave guide. In such situations, the concept of spatial diversity must be replaced by the concept of modal diversity.*

I. Introduction

Digital Transmission using MIMO has recently emerged as one of the most significant technical breakthrough in modern wireless communications. The work of Foschini, Telatar, and others [1,2] has shown that capacity of wireless systems can be greatly increased by using arrays of multiple antennas at receiver and transmitter. Telecommunication needs for public transport systems, and particularly in subways metros," are changing very quickly. In order to integrate new control command systems, and to improve passenger safety and to offer more services, it has been found necessary to have high image and data rate transmissions. One possibility had already been used GSM-R, a standard adopted in 1993 for railway transport networks in Europe. This standard uses the band 876–880 MHz for the uplink, and 921–925 MHz for the downlink [8]. The major constraint is the low available bandwidth per carrier that is equal to 200 kHz; this is not enough to carry the rates that must be of the order of 1 Mb/s for the target applications. Therefore, one potential solution is to use (MIMO) techniques.

MIMO systems use multiple inputs and multiple outputs from a single channel. MIMO (Multiple-Input Multiple-Output) systems appear to answer the needs for robust and high data rate communications, without an additional power or bandwidth consumption. In an environment full of multipath, the use of multiple antenna arrays at both the transmitting and receiving sides leads to the identification of several independent propagation channels which are linked to the rank of the channel matrix H. This analysis is being done by use of the 1800 MHz band for the Transmission and reception of the signals to get the better voice quality as compared to the 900 MHz band with the Co-operation of the Bharti Televenture Ltd at Delhi Metro region in India.

MIMO was established in IEEE 802.11n, 802.16-2004 and 802.16e as well as in 3GPP. Non-MIMO Systems are linked over multiple channels by several frequencies. The MIMO channel has multiple links and operates on the same frequency. Traditionally it is being used SISO (single input and single output) system in which the capacity increases slowly. So it is being analysed that the capacity increase is less. Now it is being used of the multiple antennas for transmission and the reception, which shows the use of the multiple antenna at the both transmission and the reception. In this type of technique by using multiple antennas at both transmission and reception the capacity improvement is not up to the mark. The transmission on multipath is due to scaterring on on obstacle . In this case the capacity is improved but as compared to the single antenna but not as much high so that the high speed transmission can be achieved. So the MIMO (multiple input and multiple output) system are used which shows the tremendous increase in capacity as compared to above.

In a multipath environment, it is often assumed that the channel connecting the transmitting and receiving antennas are uncorrelated and that the field amplitude variation displays a Rayleigh distribution. In building these assumption are usually justified given the enormous obstacle between the transmitter and the receiver. Still it is important to remember that the correlation between the fading of each channel can degrade the link performance considerably. [3]

MIMO is an extraordinarily bandwidth-efficient approach to wireless communication. It was originally developed in Bell Labs in 1995- 1997. It takes advantage of the spatial dimension .The central paradigm is exploitation rather mitigation of multipath effects. If the Fades relates transmit and the receive antenna elements which are i.i.d, than it offer a large increase in capacity [3].

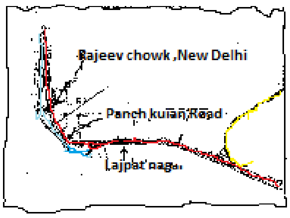
But by now MIMO models have not been understood comprehensively, especially in indoor tunnel communication systems. And in recent years a ray tracing and other hybrid methods [4] have been investigated in propagation predictions. In these methods ray tracing [5] is a useful and popular technique for predicting and modelling indoor tunnels wireless transmissions. This method allows not only the signal strength of multipath components, but also their angles of arrival and departure from transmitters and receivers, phase angle and multipath time delay. So in this investigation it is being performed the calculation of accurate factors dependents of increase in capacity of MIMO system in 1800 MHz Band with a real tunnel indoor area by using ray tracing methodology.

TUNNELS:

In the tunnel, symmetry of the translation can only generate a low spread of direction of arrival (DOA) of the rays on the receiving array, meaning a low correlation between the channels can only be due to the different hybrid mode propagating in tunnel. Two configuration of tunnel are being studied:

- A 12-m-wide two-track tunnel with a long curve extending over 200 m followed by a 100-m straight segment.
- A 9-m- wide single-track tunnel, about 300-m long.

In the tunnel when the signal is transmitted from transmitter to the receiver, the signal quality is not so much good due to the absorption of signal from walls of the tunnels and other factors so it may be used of MIMO system in tunnel to improve the capacity and also it may be used of the repeaters between the transmitter and the receiver to get the better results for long distance communication .The below shown diagram is of the tunnel when the experiment was done in Paris between the two station [4] .



Delhi Metro railway Tunnel Map

II. Ray Tracing Technique And Calculation Of Capacity Of MIMO Channel

Ray tracing technique has been emerged as a highly promising procedure providing accurate calculations of specific regions by means to obtain useful simulation results. According to ray theory, propagation takes into account direct, reflected, transmitted, diffracted, and scattered. There are lot of theories such as shooting and bouncing technique, image reflection technique, and hybrid techniques. But shooting and bouncing ray (SBR) technique is really a solution by which it can be analyse more complex scenarios than image techniques. However, 3-D SBR ray tracing technique is extremely computationally intensive and beyond the scope of the present investigations. For this reason it is being used 2-D SBR ray techniques for evaluation of Channel capacity of MIMO systems using 1800 MHz band.

Calculation of Capacity of MIMO Channel:

A slow fading MIMO system having point to point, equal transmit power and narrow band of 1800 MHz uplink and down link is being considered. And it is being assumed that the channel matrix is known to the receiver but unknown to the transmitter. In tunnels these assumptions is reasonable.

A MIMO model for point to point signal can be represented

$$r = Hs + n \quad (1)$$

where r is the M x 1 received signal vector, s is the N x 1 transmitted signal vector and n is an additive noise terms, assumed i.i.d complex Gaussian with each element having a variance of equal to σ^2 , H is M x N Channel matrix. Resulting upon, The capacity of MIMO channel system is given by,

$$C = log_2 [\, det\, (I_M + (\rho/ n_T)\, HH^H) \quad (2)$$

Where C = capacity of system, I = identity matrix, ρ = signal to noise ratio, H = matrix of order receiver.

So the parameters can be used to obtain from ray tracing theory to get the instance of H matrix of MIMO system. The impulse response between a specific transmitting and receiving antenna pair is modelled as the vector sum of the entire ray arriving at the receiving antenna as [7,8].

$$g_{ij} (t) = \Sigma\sqrt{P_{k.}} e^{j\Theta}{}_{k}\delta(t-\tau_k) \quad (3)$$

Where P_k , Θ_k , and τ_k are the received power , phase angle and time delay of the kth ray, respectively. M is the total number of rays and δ (t) is the delta impulse function. With narrow band of 1800 MHz band assumptions, it may be computed the frequency response at infinitesimally small bandwidth centered at the carrier frequency as

$$H_g=\Sigma\sqrt{P_k}.e^{j\Theta_k}.e^{-j2\pi f\tau} \quad (4)$$

H is constructed and computed using (4), P_k, Θ_k, and τ_k are obtained from ray tracing theory. All the n^2 elements h, are complex numbers in this consideration. Place the Rx antennas at 500 randomly positions in the different points in moving train in corridor of tunnel. It may be assumed that average received SNR may be high enough for low bit error rate communication and may be 12 to 18 dB. When it is being taken expectation with respect to different realisations of H, it means to taken the ensemble average over 500 sample receiver points. And then capacity complementary cumulative distribution functions may be obtained.

As shown in Figure 1, it may be considered the indoor tunnel corridor wireless environment of one way and two way track. The transmitting multiple element arrays may be placed in the corridor. Receiving MEAs may be placed with randomly moving train along y axis and x- axis in different coaches of train. Thus transmitter and receiver the Channel may be considered as non line of sight.

According to Figure 2, transmitting MEAs may be placed in position B and receiving MEAs may be placed with randomly moving in train along y axis and x axis in position C. Then there exists a line of sight path between Receiving and Transmitting elements. In this experimental study, it is being considered a carrier frequency of 1.8 GHz and 5.1 GHz. i.e wavelength λ = 1.6 cm and λ = 5.7 cm. The MEAs may be arranged of multiple Omni-directional antennas, arranged in linear arrays with horizontal planes. The antenna spacing d may be same at the both the transmitting and receiving MEAs.

Positioning the array elements

To minimize the correlation between the antenna elements, a variety of test were conducted for 2 orientation of the array axis, one parallel to the tunnel axis and the other perpendicular to the tunnel axis. A third configuration, in which the angle between the array axis and the tunnel axis is approximately 45, was also tested. According to the calculation of the channel capacity deduced from the formula, the array axis running parallel to the tunnel axis produces the worst results [8] .

Model approach:

The tunnel acts as a waveguide so the different types of the modes exist inside the tunnel the mode exist in the waveguide if we consider a rectangular tunnel along the *z*-axis with cross-sectional dimensions (x, y) = (a, b). We place the coordinate origin at the center of a cross section and at z = 0, which defines the excitation plane. Let the excitation be a *y*-directed (vertical) dipole. The natural modes supported by such a structure are *y*-directed (vertical) hybrid modes $EH_{m,n}$ of index m, n. Any electric field component $E(x, y, z)$ can be expressed as a model sum [6]:

$$E(x,y,z)=\sum_m\sum_n \alpha_{m,n}e_{m,n}(x,y)$$

Where $e_{m,n}$ (x, y) is the modal eigen function, and $\alpha_{m,n}$ (z) is the modal coefficient at any cross-sectional plane defined by [6]:

$$\alpha_{m,n}(z)=\beta_{m,n}e^{-jk_{m,n}z}.$$

In tunnels, the number of modes significantly contributing to the total power at the receiver is an important parameter for interpreting the capacity of a MIMO system. Therefore, we consider the number of "active" modes $Na(x\%)$, defined as the number of modes whose powers are equal to at least x% of the power in the most powerful mode. Since the weight of each mode depends on the position of the transmitting array element, The number of active modes in the tunnel decreases as the distance increase so hence the capacity of the system will also start decreasing at larger distance.[6] The below shown the illustration of tunnel and train configuration [8]:

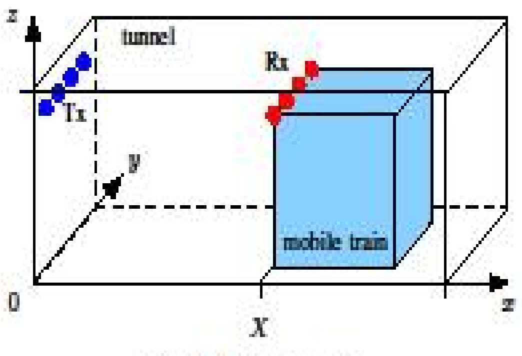


Figure 1.: 1 track empty tunnel

On today high capacity transmission is possible using different modes of tunnels in MIMO systems. Many measurements campaigns have been carried out considering the complicated geometric structure of these tunnels. An experimental study is being carried out in Delhi metro tunnels. It is being observed that the antenna alignment plays a critical role due to the wave guide effect of the tunnel. Best performances are obtained when the antennas are aligned perpendicular to the centreline of the tunnel or are placed along a diagonal. Preliminary results given in, [4] and [7], have shown that MIMO may improve the channel capacity for short range communication. In a multipath environment, it is often assumed that the channels connecting transmitting and receiving antennas are uncorrelated and that the field amplitude variation displays a Rayleigh distribution. In building these assumption are usually justified given the enormous obstacle between the transmitter and the receiver. Still it is important to remember that the correlation between the fading of each channel can degrade the link performance considerably [3]. The fading correlation affects the MEA capacity by modifying the distributions of the gains of these sub channels. The fading correlation depends on the physical parameters of MEA and the scattered characteristics.

The various experimental studies have been carried out considering the complicated geometric structure of these tunnels. The GSM-R is used for the communication which have the carrier frequency of 900 MHz and the bandwidth associated with this kind of the communication link is 200 KHz [7], by using this band in the communication, it is being achieved a poor voice quality when the communication is made in the long tunnel. So a higher Frequency band may be used to obtain a better voice quality, the repeater is also necessary for the maintaining the good signal strength which is not used in the previous experimental studies. So to make the communication reliable and efficient the repeaters are necessary, preliminary results given in, [3] and [7], have shown that MIMO may improve the channel capacity for short range communication. By using the repeaters it can be improved the capacity for long range communication. In the small tunnel, because of the reduction in the number of modes and because of correlation effects, the capacity monotonically decreases [6]. These are the some gaps which must be minimized, to minimize these gaps it is being made use of the repeaters to obtain good signal strength at the receiver. A higher frequency band is used that is of 1800 MHz to improve the voice quality during the communication.

III. Results

MIMO performance with Non- line of sight in Tunnels:

The Configuration of 4 X 4 and 8 X 8 pattern of antenna system with spacing of 0.1λ , 0.3λ, 0.4λ, 0.5λ , 1 λ and 5λ may be considered by using ray tracing technique in tunnels and i.i.d. Rayleigh channel capacity may be analysed by Monte Carlo simulation method as shown in figure 2.

The Figure 2 and figure 3 shows that spacing in antennas may affect the MIMO system channel capacity distinctly in tunnels. For 4 X 4 and 8 X 8 antenna based MIMO with maximum spacing in consideration of 5λ, the capacity of a system with CCDFS in tunnels may be reached the i.i.d. Rayleigh channel capacity nearly fully. If the spacing between antennas may decrease than result shows the decreasing capacity of system. When the spacing may decrease by 0.1λ, the MIMO channel capacity drops significantly and all capacity gains predicted by Foschini and Telatar may be unjustified.

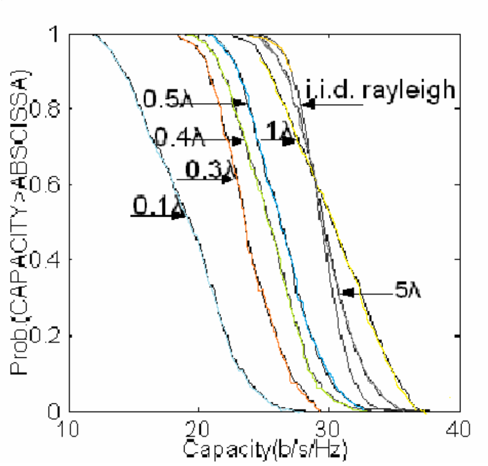


Figure 2: 4 X 4 configurations Patterns with N-LOS

MIMO performance with LOS in Tunnels:

The configuration of 4 X 4 and 8 X 8 pattern of antenna system with spacing of 0.1 λ, 0.3 λ, 0.4 λ, 0.5 λ, 1 λ and 5λ may be considered by using ray tracing technique in tunnels and i.i.d. Rayleigh channel capacity using Monte-Carlo simulation method present in Figure 4 and Figure 5 respectively using line of sight pattern of the system.

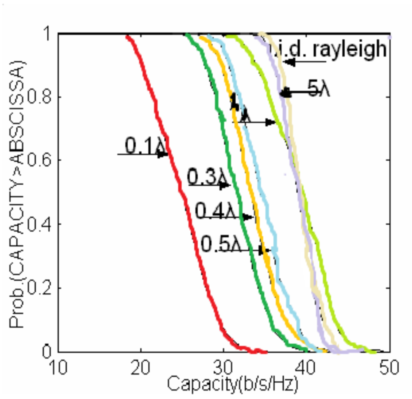


Figure 3: 8 X 8 configurations Patterns With N-LOS

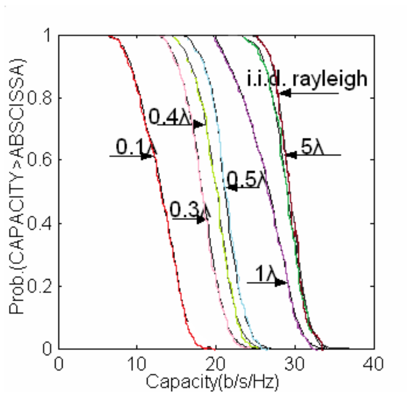


Figure 4: 4 x 4 configurations Pattern with LOS

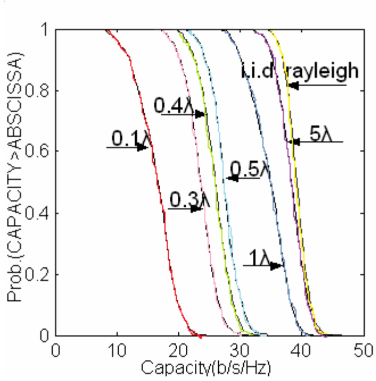


Figure 5: 8 X 8 configurations Patterns with LOS

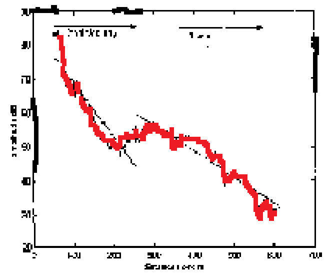


Figure 6: Variation of power of Mobile moving from two way tunnels to single way tunnel. [3]

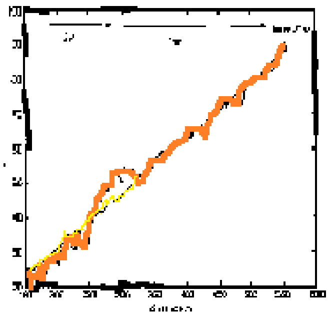


Figure 7: variation of received power of Mobile moving in one way to two ways Tunnel. [4]

IV. Conclusion

MIMO Techniques based on multiple Antennas at both the transmitting and receiving sites use multipath to transform the overall channels into numerous independent virtual channels. However, when the link is made in long tunnel, the number of reflecting object, or near the transmitter is quite low. In addition due to the large transverse dimension of tunnel compared to the wavelength, the tunnel acts as a lossy oversized waveguide. The Channel capacity using 2D ray tracing technique in non line of sight in Tunnels and with LOS path is being observed and compared with the i.i.d. Rayleigh channel capacity. The result shows different propagation techniques may affect the channel capacity greatly in tunnels. Whether in 900 MHz [4] band with a poor voice quality in the tunnels was being achieved in previous investigations. In this Experimental study by using 1800 MHz band in which the better voice Quality may be maintained with achievements of higher channel capacity and the distortion is less. The applications in 3G and 4G systems, using MIMO system in Tunnel, to obtain a much greater capacity and the higher data rate without utilizing the extra bandwidth in fading environment can be a part of future investigations. It may be usage of MIMO system in future advanced communication systems in the tunnel to obtain the better results.

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