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Application of Rayleigh Theory for Propagation of MIMO Signal through Tunnels

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***Abstract*— Multiple-Input Multiple-Output is a wireless technology that uses multiple receivers and transmitters to transfer more data or information at the same time. MIMO technology is mainly used to improve the communication performance. This technology is primarily used to increase their data rate instead of improving the robustness and also more attracted in the area of wireless communication. MIMO achieves goal by spreading the overall transmit power through the antennas to obtain array gain and improves the spectral efficiency. The implementation of MIMO systems in tunnels to improve data rate and data quality by using multiple Tx and Rx antennas. MIMO techniques are based on multiple antennas in receiving and transmitting signals and also used in multipath propagation for the transformation of entire channel into many independent virtual channels. This study discusses about the application of Rayleigh's and Modal theory of electromagnetic propagation in circular or rectangular tunnels and also investigated by some experimental results. This paper describes about the propagation of MIMO through tunnels by many algorithms, ray approaches, various applications and functions of MIMO technology.**

***Index Terms*— CSI -Channel State Information,H- channel matrix, MIMO- multiple input multiple output, Rx- receiver, SBR- Shoot, Bounce and Reflect, VNA -Vectorial network analyzer.**

I. INTRODUCTION

An Introduction to Rayleigh Theory:

Rayleigh Theory describes that in the light scattering off a small particle in an ideal solution. The electromagnetic field is light.At the origin the field factor is time dependent and described by :

$$Ez = E0 \cos(2\pi ct/\lambda) \quad (1)$$

In the equation 1, c is the speed of the light, E0 is the amplitude of the electric field and λ is the wavelength of light. The subscript z on E is considered to be light polarized with the plane polarized light along with the Z axis.

Figure 1: Plane polarized light with the light polarized in the z direction and incident on a small particle.

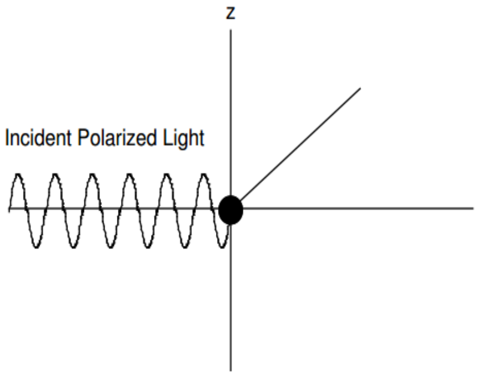
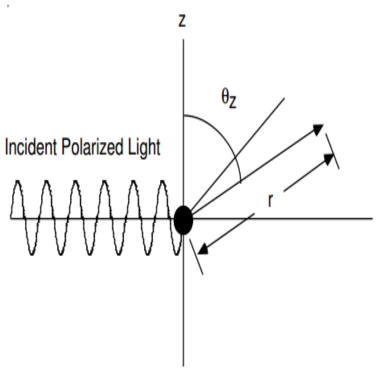


Figure 1 shows that an incident beam of the light polarized in the direction of the z. If the particle at the origin showing in the figure 1 is polarizable, then the incident electric field will provoke a dipole moment in that particular particle.The field is proportional to the magnitude of the dipole moment.

αp is the proportionality constant which is called polarizability.The higher the magnitude of dipole moment is the higher a particle's polarizability is induced by a given electro magnetic field.In the equation (2) the dipole moment is shown

$$p = \alpha p E0 \cos(2\pi ct/\lambda) \quad (2)$$

Figure 2: Observation direction for the light scattered particle at the origin in a direction that makes an angle θz with respect to the z axis.



In all directions the induced dipole moment will radiate the light.Figure 2 shows that observation of the scattered or radiated light at a distance r from the origin in a direction along a line which makes an angle θz with the z axis.The scattered or radiated field will be proportional to (1/c-2)(d2p/dt2).The second derivative of p is the acceleration charge on the dipole moment.Including the spatial efforts the scattered light is proportional to 1/r and projection of dipole moment on observation direction (sin θz).By combing all these efforts for the electric field,light is scattered in the θz direction is

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Es= 1/r 1/c2 d2p/dt2= -1/c2 αpE0 4 4πc-2/r λ2 sin θz cos (2πct/ λ) (3)

Equipment which measures the scattered light is sensitive to the intensity of the light.The amplitude of the electromagnetic field squared is equal to the intensity of light.The squaring of the amplitude of Es which gives the scattered light intensity at θz and r.

Is= = α2pI0z 16 π4/r2 λ4 sin2θz (4)

In the equation (4) I0z is the intensity of the z polarized incident light

I0z = E20 (5)

Experiments are usually done with the unpolarized light.By the unpolarized light by summing up the intensity of equal parts of the incident polarized in both the y direction and the z direction.The incident intensity which becomes

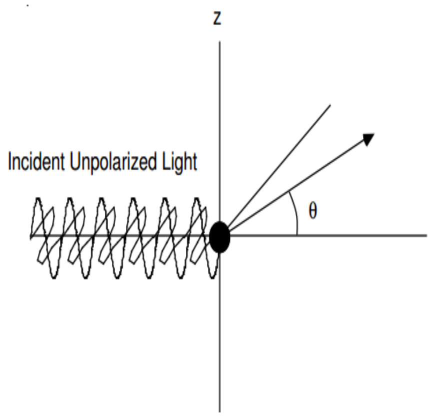
I0 =1/2I0z +1/2I0y (6)

and then the intensity of the scattered light becomes

Is =1/2Isz +1/2 Isy = I08π4α2p/r2λ4(sin2 θz + sin2 θy) (7)

In this equation (7) θy is the angle of the observation direction makes with the y axis.

Figure 3:Scattering of unpolarized light is analyzed by considering in both the directions of z and y directions by scattering the incident light polarized.



By the geometry terms of θz and θy can be related to the angle of θx in that the observation figure 4 direction makes with the x axis. The angle direction is simply referred as θ.That is the total sum of the direction cosines is 1.

cos2 θx + cos 2 θy + cos 2 θz = 1 (8)

then the geometric result is easily derived,

sin2θz + sin2θy = 1 + cos2θ (9)

now we have the scattered light intensity for the scattering off single particles.For scattering off nL particles (L is the number of Avagadro's) or n moles of particles in a dilute solution of the volume V, the scattered intensity at θ is:

i0θ =I0nL/V 8π4 α2p/r2λ4(1 + cos2θ) (10)

The superscript 0 on the I indicates which is scattered due to the small molecules.

The scattering angle depends on the light scattering.intensity. By the (1 + cos2θ) the shape of the diagram is determined.

II. RAYLEIGH THEORY THROUGH TUNNELS AND MIMO:

The Multiple input multiple output (MIMO) wireless communications systems are the systems which have the multi element antenna arrays at both the receiver and the transmitter side. Several independent communication channel systems that provide the potential for the large information capacities between the transmitter and the receiver[2].

In an ideal multipath channel the Multiple input multiple output capacity is approximately N times in the capacity of a single antenna system, here N is the smallest number to receive or transmit antenna elements. The correlated signals at the antenna elements will lead to decrease in the capacity[2][3].

It has been predicted that the Multiple input multiple output (MIMO) channel capacity is very low when compared to the Single input single output (SISO) channel capacity even though the signals at the antenna elements are being uncorrelated. This kind of effect has been named as a pinhole or keyhole. This is related to the receiver will lead to low correlation signal level while other propagation effects like wave guiding or the diffraction that leads to the rank reduction of the matrix function which transfers[17].

When the Multiple input multiple output maximum capacity techniques are implemented in the tunnels especially in the subway tunnels. There is an increasing demand in improving the effective transmission bit rate between a track and train. Most of the new command and control systems of automatic subways mainly based on an exchange of an amount of data which must be conformed even in the underground part of the subway line. It is proved recently that the multiple input and multiple output techniques has improved the channel capacity but only under the condition of a small correlation paths between each transmitting and the receiving antenna[8].

Chuah, Tsc, Kahn, Valenzuela (2002) refers that in a tunnel the same problem in a long corrider the more or less the good translation symmetry which does not give rise to a wide spread of the DOA (direction of arrival) of the rays at the receiving site or move to an important decorrelation. The tranverse dimensions of the tunnel are much more greater than the wavelength, the superposition of the numerous hybrid modes which is supported by the structure is due to the decorrelation. Further a good decorrelation between the antennas for the high capacity will not be guarantee because if the tunnel behaves as a model key hole the channel matrix can be degenerated [15].

It is not possible to implement the antennas on the tunnel ceiling practically and they have to put on a platform near the track. Choosing the tyoes of antennas and their radiation pattern is the first step. The first idea is to consider the omni directional type of antennas at least should be in the horizontal plane. Most of the energy propagates along the tunnel axis is due to the guiding structure of the tunnel and lack of big obstacles. To increasing the channel capacity compromise must be found. To increase of the mean signal to

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the noise ratio by using the directive antennas or to get profit of a spread of the direction of arrival. The preliminary experiments have been shown that the average direction of arrival spread angle is smaller or in the angle 90 degree. For this type of trails horn antennas,the platform 12dBi gain is used. In order to check the validity of this trails , additional trails have been made with the bertical half wave dipoles.The channel capacity deduced the configuration,assuming the same signal to the noise ratio.It was not possible for the security reasons in the train to place the quarter wavelength monopolies on the roof and for this the only solution have to put the antennas behind the windscreen. These antennas were placed in order to maximize the decorrelation at each corner. The Channel sounder is mainly based on a technique of correlation and has a bandwidth of 35 MHz and has a centre frequency of 900 MHz. This bandwidth is very much greater than the necessary bandwidth of the final system[14].

III. Design and implementation

The development of channel capacity is obtained by using MIMO (Multiple Input Multiple Output) techniques. It is the best method to enhance the communication performance in a tunnel environment and highly useful for urban, sub-urban and indoor environments. Thus, the characteristics of propagation through tunnel are quite different and their rays impose to the walls of tunnel with grazing angle of incidence without endure a heavy attenuation for the entire field. The departure of ray is relatively small and the techniques of MIMO produce many interesting results. Theoretical and Experimental research shows that the capacity of channel is nevertheless improved with the help of Multiple Input Multiple Output techniques. For more better results are obtained from transmitting (Tx) and receiving (Rx) array elements are associated with perpendicular to the axis of the tunnel. The performance of MIMO algorithms are also explained in channel characteristics of MIMO and their theoretical modeling of propagation based on the modal theory.

Spatial fluctuations of Rx signal because of the interference between two modes, fading distribution that leads to a Rayleigh distribution. The performance of Multiple Input Multiple Output (MIMO) systems depends on the condition number of H matrix as denoted in the ratio of the highest Eigen values. However, two MIMO algorithms are measured to estimate the condition number and those algorithms are regarded as OSTBC, VBLAST or QSTBC codes. A Mat lab based software tool was developed for increasing communication link; then the input for this software tool is measured by using H matrices. BER (Bit Error Rate) was deduced by estimated symbols, many transmitted Rx symbol for every channel realization and the bit error rate received by using VBLAST algorithm.

The implementation of simple ray-shooting package by using MATLAB for visualizing ray paths in the ground wave propagation simulations. This ray-shooting package is useful for wave propagation model but in complicated wave guiding environments with the help of an educational tool i.e. Electromagnetic (EM) defines a special design tool for visualizing GO (Geometrical Optics) rays for reflection, refraction and propagation. The electromagnetic wave propagation occurs in complex environments and also to perform in the area of wireless communication system. Propagation engineers, Service planners and site-surveyors, etc., within their organization keen to access in real time for the characteristics of propagation given on digital map in a computer, by choosing specific locations of transmitter or receiver pair are more useful. In field-strength prediction has been simulated to two dimensional paths and also used by propagation along with two dimensional paths overcome particular problems during investigation. The Mat lab package carries out user supplied input parameters, maximum range of layer height, height, source of location, first and last ray angles can be measured from normal surface, tri-linear refractivity parameters, ray increment and obstacle heights, locations, and this package helps to begin the ray-shooting techniques. This study targets a simple MATLAB package for visualizing ray paths based on two dimensional in complex environments along with variable refractivity profiles and obstacles.

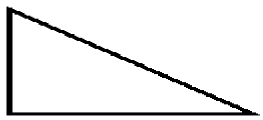
The ray tracing propagation model depends upon their frequency-time and frequency-domain techniques are briefly explained in this section. The complicated portion of propagation simulation of ray predicts the path of the rays between the transmitter and receiver. The two ray paths such as reflected and refracted rays are produced by using two alternative methods namely Eigen ray search and Brute force. Eigen ray search is used to identify properties of rays between the transmitter and receiver through the propagation path. Brute force is useful for the purpose of bouncing and shooting rays. It is shortly called as SBR. This force determines a bundle of transmitted rays that can or cannot reach the receiver's end. Hence, it is taken as a challenge for ray-tracing techniques and calculated rapidly to specifying dominant ray paths that helps to predict the field-strength. It also acts as a research tool for the prediction of ducting and non-ducting conditions in many refractive profiles.

IV. Results Of Various Shapes Of Tunnel Configurations.

Tunnel 1

The following are the configurations for various coordinates of the triangular tunnel

Z1= 300
Z2= 500
Z3= 1000
Z4=1200



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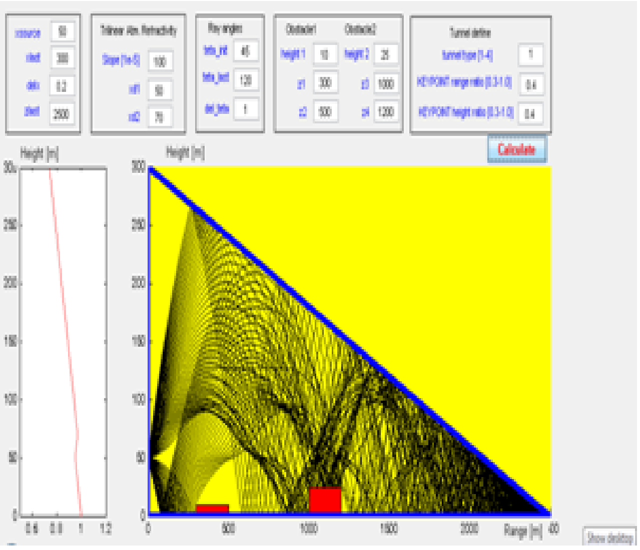


Fig : Ray diagram of tunnel 1

Tunnel 2

The following are the configurations for various coordinates of the arch shaped tunnel

Z1= 300
Z2= 500
Z3= 1000
Z4=1200

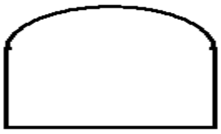
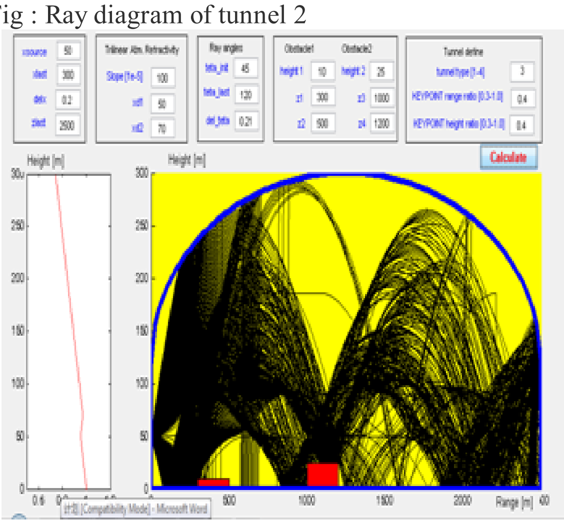


Fig : Ray diagram of tunnel 2

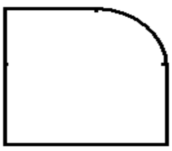


The above is the ray diagram shot for the second tunnel.

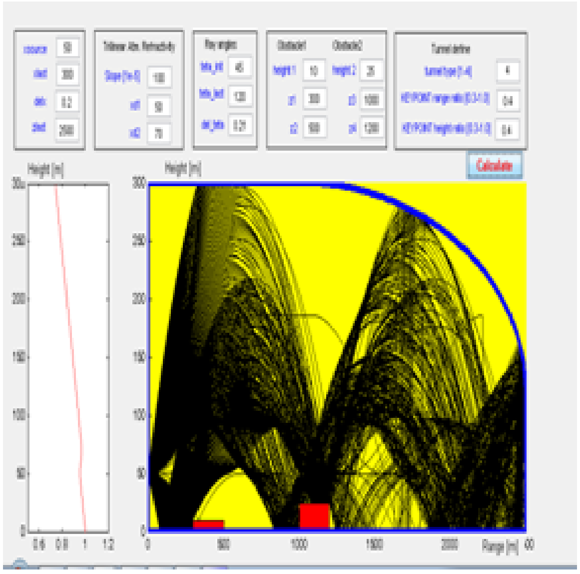
A. Tunnel 3

The following are the configurations for various coordinates of the arch shaped tunnel

Z1= 300
Z2= 500
Z3= 1000
Z4=1200



The following is the ray diagram shot for the third tunnel box, making the layout look confusing.



V. Recommendations for Future Research

The current research has implemented the propagation of MIMO channel through tunnels exclusively using MATLAB. The study could also be extended using other forms of software packages and simulators such as Java, simulink, NS2 etc. The present study has created a ray diagram for only four simple shapes of tunnels. In future, more number of shapes that are much complex could be tried by the researchers. In this study results are drawn purely based on Rayleigh and Modal theories. Further, the researcher while designing the tunnel has considered only two forms of obstacles which could be extended by the future researchers based on the prevailing environment. The study could be further refined using other forms of theories of wireless communication. Finally this research has been conducted only based on the SBR method to shoot the ray diagrams. The future researchers can try different methods such as image method in order to trace the propagation of MIMO channels in tunnels.

VI. Conclusion

The propagation of MIMO channel is deduced from Modal theory and Rayleigh's theory that highly differs at a distance between the transmitter and the receiver end. By using many algorithms, it is used to increase the correlation among two array elements. The implementation of MIMO in wireless communication greatly facilitates for spectral efficiency, link reliability, better performance and high rate of transmission. On the other hand, Matlab package are more helpful for beginning the ray-shooting techniques. These main packages should be used as an educational tool in various components by using antennas and propagation, wireless propagation and Electromagnetic Wave theory. The user able to develop MATLAB code by using more obstacles is distinguished in the Mat lab package. MIMO techniques are often used in many wireless technologies such as Wi-Fi and LTE (Long Term Evaluation) standards. The Wi-Fi devices make use of multiple antennas to transmitting and receiving signals at the

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same point of time. Although, it is used to reduce the bit error rate and provides an outstanding performance of MIMO configuration based on the application of Rayleigh's theory.

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