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# Modeling of MIMO propagation in Tunnels

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**Abstract**— Wireless communication draws the attention of various and this is because, it increases in data throughput and also the link range without the increased transmit power or additional bandwidth. The explanation and/or prediction of the inside distribution field such tunnels are excited by the electric antenna which is essential for deployment of wireless communication system. Primary objective of the study is to understand and model propagation of multiple input multiple output channel through a tunnel. Secondary objectives are to analyze the applications of modal theory, To explore how modal theory can be applied in identifying MIMO propagated through tunnels and to simulate MIMO propagation through tunnel using MATLAB..

**Index Terms**— H- channel matrix, MIMO- multiple input multiple output, MATLAB- matrix laboratory MISO- Multiple Input Single Output, OFDM- orthogonal frequency division multiplexing, Rx- receiver, SBR- Shoot, Bounce and Reflect, Tx- transmitter.
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## 1 INTRODUCTION

Mapping of the single data stream into the multiple parallel data streams and also de-mapping of the multiple received data streams into the single data stream is known as MIMO (Multiple-Input Multiple-Output). Multiple-Input Multiple-Output provides high data rate and high spectral efficiency. In Multiple-Input Multiple-Output multiple antennas are used both at the receiver and transmitter side to improve the communication performance.[1].

Multiple-Input Multiple-Output technology has draws the attention of wireless communication because, it increases the data throughput and also the link range without the increase of transmit power or additional bandwidth. Multiple-Input Multiple-Output achieves its goal by distributing the total transmit power through the antennas in order to obtain array gain which improves the spectral efficiency or to obtain the diversity gain which improves the link reliability. All these properties make Multiple-Input Multiple-Output as an important part in the modern wireless communication standards [1].

Implementing MIMO (Multiple-Input Multiple-Output) systems in tunnels is generally to improve the communication performance but since it is known that decrease of the error rate and/or high data rate can be achieved [2].

In the tunnel, the number of random scatterers may be small and the application of Multiple-Input Multiple-Output concepts to the waveguide will based on propagation of the orthogonal modes

and each mode should be associated with diversity order [3].
The following figure illustrates the basic diagram of MIMO (Multiple-Input Multiple-Output).

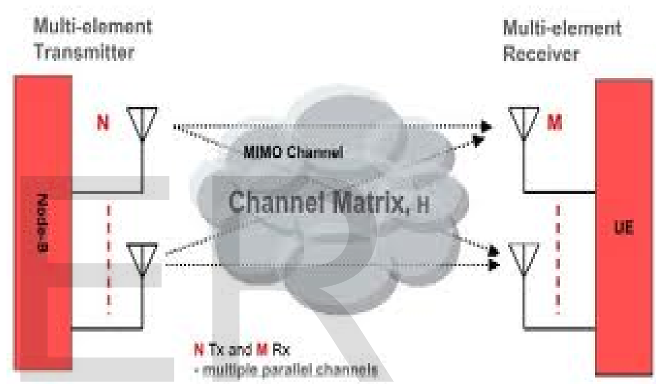


Fig 1: Multiple-Input Multiple-Output (MIMO)
Source: [18]

**Advantages of Multiple Antenna Techniques** are Increased coverage, Reduced power consumption, Increased capacity, Improved spectral efficiency, Increased data rate, Resistivity to fading (quality),Reduced cost of wireless network[17]

## 2 MIMO PROPAGATION AND CHANNEL MODELLING

Mostly Multiple-Input-Multiple-Output systems are designed for the moving terminals. Multiple-Input-Multiple-Output channels provides support for the parallel data streams by receiving and transmitting on orthogonal spatial multiplexi ng (spatial channels)[4]. The number of multiplexed streams depends upon the rank of instantaneous channel matrix $H$ than it depends on spatial properties of radio environment. Then the spatial multiplexing gain will reach $min(m,n)$ in rich scattering

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so it is essential to consider what rich scattering means and its relative importance. Knowledge about instantaneous MIMO channel is important for the system engineers. Whether CSI (Channel State Information) is available at the transmitter or the receiver, or both, whether this information happening in a moment, actual channel will result in entirely different transmit and receive strategies. Diversity, multiplexing and Beam forming are very competitor techniques. Only the initial, introductory paragraph has a drop cap. In order to highlight the role of propagation channel, the trade-off between multiplexing, beam forming and diversity are broken down into many dichotomous trade-offs[4].

The following figure gives vision to how the diversity or directivity at the transmitter and receiver ends of MIMO link determine to the extent that the channel supports multiplexing, beam forming and diversity.

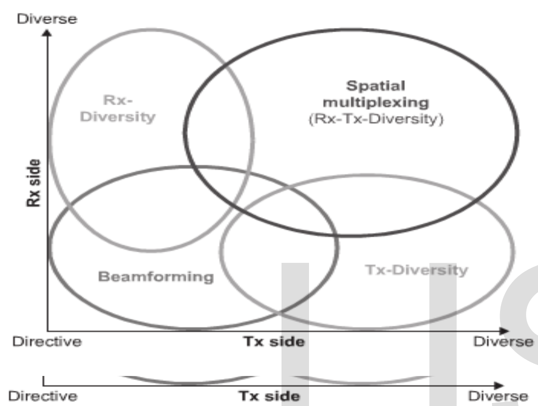


Fig 2: Channel supports multiplexing, beam forming and diversity
Source: [4]

First, optimal trade-off between diversity and multiplexing on hand and beam forming on the other hand is provided to channel properties as similar to the trade-off between diversity and beam forming in the case of MISO. A directive channel that favors adverse (non-directive) beam forming channel allows multiplexing and/or diversity. Second, there is trade-off between multiplexing and diversity. This trade-off is dictated by channel. If one side of Multiple-Input-Multiple-Output link is purely directive and there is no possible for multiplexing but diversity will be exploited at uncorrelated link end [4]. MIMO channel modeling is of two types:

- Physical based modeling
- Non physical modeling

i)
ii)
iii)

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The physical models of Multiple-Input Multiple-Output describes about the Multiple-Input Multiple-Output channel or its distribution with some physical parameters. The non-physical models basically rely on statistical characteristics of Multiple-Input Multiple-Output channels that are obtained from measured data [16].

Following figure illustrates this approach.

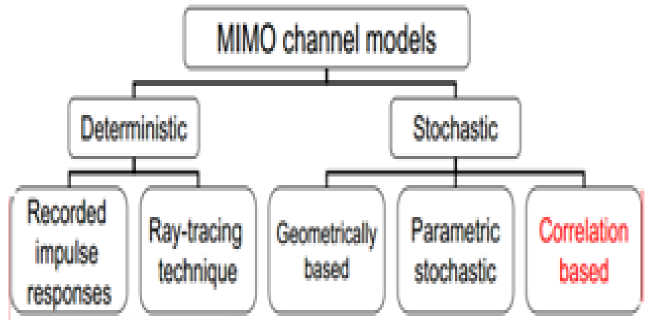


Fig 3: Classification of MIMO channel models
Source: [16]

## 3 HOW CAN MIMO BE PROPAGATED THROUGH TUNNELS

New technologies of information and communication are key components for the transit systems with applications such as embedded surveillance, video on demand, maintenance reporting and control and command [5]. These wireless systems are deployed using the antennas, wave guides or radiating cables using free propagation in tunnels. It is essential for the wireless systems to maximize data rate or robustness and it is essential to avoid the increase of transmission bandwidth or transmitting power.

Multiple-Input Multiple-Output (MIMO) systems introduced to answer the needs for high data rate communications and robust without the additional bandwidth or power consumption [6]. In the multipath environment, use of the multiple antenna arrays at both the receiving and transmitting sides leads to identification of many independent propagation channels that are linked to rank of channel matrix $H$ [7]. The capacity of Multiple-Input Multiple-Output channel depends on the rank. With the key hole or spatial correlation effect in channel, the $H$ matrix will be degenerated [8]. This will be the efficiency and interest of such system is suitable for the transport environments [9].

## 4 PROPAGATION CHARACTERISTICS

The characteristics of propagation in tunnel consist of three steps. They are:

1. Geometry of the tunnel and Measurement procedure
2. Principle of Theoretical modeling and
3. Path loss and fading distribution

### 4.1 Geometry of the tunnel and Measurement procedure

Measurements can be carried in straight arched empty tunnel at a distance of 3km [15]. The transverse part of tunnel is semi-circular and its diameter of cylindrical section is 8.6m. The actual height of center point of the tunnel is 6.1m. Wideband

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bi-conical antennas are joined to 2 ports of VNA (Vectorial network analyzer) and its frequency ranges between 2.8-5 GHz. But in this study, only concentrate on narrow band Multiple Input Multiple Output channels in the order of center frequency is 3GHz. However, few results obtain between 4 and 5 GHz. A transmitting and receiving antenna moved on a rail located at a height of 1 meter over the ground and its mechanical system is controlled by stepper motor. These rails are positioned perpendicular to the axis of tunnel. Both antennas Transmitter and Receiver are moved in spatial step of 3cm with a distance of 33cm as explained and this leads to twelve successive positions in transverse plane. Thus, it will be feasible to analyzing the channel characteristic of MIMO depending upon virtual Transmitter and Receiver arrays. The highest distance of 33cm is chosen in accordance through implementation constraints of any array on the top of a vehicle [15].

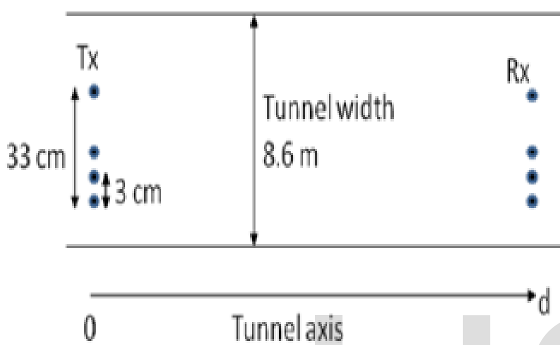



Fig 4. Configuration of the virtual Transmitter or Receiver arrays inside the tunnel
Source: [16]

In tunnel axis [15], the distance between these two arrays Transmitter and Receiver vary from 50 m to 500 m. The rail sustaining receiving antenna Receiver moved a step i.e. equivalent to 4 m (50m < d < 206m) and for 6m (206m < d < 498m). Avoiding prohibitive attenuation in cables joining the antennas and its network analyzer the signal of transmitting Transmitter port is transformed into an optical signal passed by fiber optics. It's again transformed into radio frequency signal and amplify an output power is 1w. This measurement procedure of vectorial network analyzer brings all electronic and optical components into an account. During measurements the channel is stationary (fixed) because the tunnel close to traffic.

# 5 IMPLEMENTATION

## 5.1 Implementation of Ray theory

The ray theory is associated with an image theory and provides a group of virtual transmitting antennas Transmitter. The shape of tunnel is rectangular cross-section area and determined its locality with the virtual antennas is entirely straight forward. It is also independent of location from their receiver's end. The entire field is obtained by adding all rays connected along with images and its receiving point and depending on the co-efficient of reflection around the tunnel walls. Hence, by considering propagation of ray, the total contribution of all rays at their receiving point Receiver should obtain the nature of vector in an electric field.

For every reflection on a tunnel wall, the vector of an electric field can be expressed by the summation of two components such as: A perpendicular ray is at the plane of incidence $E_{perp}$ and another ray parallel to $E_{perp}$ plane. In both of these two components have reflection co-efficient values of $R_{TM\ and}\ R_{TE}$ correspondingly. These two values are regarded as mathematic expressions and applied in this theory. The expressions indicate the concept of propagation of an electromagnetic wave [12][13]. In a reflection, one should receive the new kind of orientation of an electric field vector.

According to [10], the distance among Transmitter and Receiver become higher than thrice times as compared to greatest dimension of cross section area of the tunnel and its waves are linearly polarized. From this method, the sum of vector for electric field is radiated through an antenna and their images are quite simple scalar as in equation. The equation can be written as:

$$E(x,y,z) = \sum_m \sum_n (R_{TM})^m (R_{TE})^n E_d\,(S_{mn})$$

Here $E_d$ $(S_{mn})$ indicates an electric field which radiates in free space through an image source *Smn* and equivalent to its rays with 'm' reflections around the tunnel wall perpendicular to the axis of dipole Transmitter and 'n' reflections on the tunnel wall parallel to axis of dipole [13]. These subsequent examples are the excitation through an electric dipole may be regarded; as a result it is not a heavy restriction of approaches of ray. Therefore, other types of antennas could be treated with the help of introducing its free space of radiation pattern in this method. By weighting, rays in a specified direction through a factor directly proportional to antenna gain in the same direction.

Finally, it should be emphasize the reflection coefficients in the walls of tunnel leads to one. Let us assume, the angle of incidence based on reflecting planes tend to 90°. It means that taken for long distances the rays only impinging the tunnel along a grazing incident angle acts a significant component in its received power. Then the number of rays which fulfills particular condition is very important. In general, the prediction of entire electric field in typical tunnels needed at a distant of 100 meters. An individual must observe that if a base station is situated in the exterior part of the tunnel and mobile moves in interior portion of tunnel. Thus, the ray theory could be applied in the diffraction on the aperture plane of tunnel wall [10].

## 5.2 Implementation of Modal Theory

The normal modes of propagation in an inner portion of the tunnel are called as hybrid modes. It is denoted by the symbol $EH_{mn}$. According to [11], it has three components of the magnetic and electrical fields are there. The parts of an electrical field E(x, y, z) can be defined as the summation of total modal parts are [11]:

$E(x,y,z) = \sum_m \sum_n A_{mn}(0)\, e_{mn}(x,y)\, e^{-\gamma_{mn} z}$

From the above expression, $A_{mn}(0)$ is a mode of complex amplitude in the excitation plane; $e_{mn}$ is a normalized mode of Eigen function and $\gamma_{mn}$ is a constant of complex propagation. This can also be written in the form of:

$\gamma_{mn} = \alpha_{mn} + j\,\beta_{mn}$

The component field of variations contains the value vicinity of Transmitter. This trend will have a great impact based on the correlation between two array elements which are used in MIMO systems. Consider a vertical transmitting elementary dipole is located at $x_{tx},\ y_{tx}$ the entire electric field at their receiving point (x, y, z) can be given in the order of [14]:

$E(x,y,z) = \sum_m \sum_n e^{V}_{m.n}(x_{ix}, y_{ix})\, e^{V}_{m.n}(x,y)\, e^{-\gamma_{mn} z}$

In most common cases, the structure of radiating pattern presents in a free space and get an easy solution to distinguish the weight of modes in the plane may be proceed in two different steps. The first step, an E field in tunnel is computed mathematically by using ray theory and the weight of any mode $\boldsymbol{A_{m.n}(Z)}$ (m, n) for an abscissa can be acquired by projecting the electric field based on $\boldsymbol{e^{V}_{mn}(x,y)}$. This is denoted as follows [14]:

$A_{mn}(z) = \int_{-a/2}^{a/2} \int_{-b/2}^{b/2} E(x,y,z)\, e^{V}_{m.n}(x,y)\, dxdy$

Based on this mathematical application, significant values can be measured; the electrical parameters of the wall of tunnel. The radiating element is a elementary dipole located from the portion of ceiling and 1/4th part of width of tunnel and the transmission frequency is 900 MHz. This kind of configuration could equivalent to location of a base station antenna in real tunnel.

### 5.3 IMPLEMENTATION OF RAY TRACING METHOD

This is considered as a challenge for ray-tracing technique [19] to determine and calculated as fast in order to specifying dominant ray paths taken into account to predict its field-strength. It is shortly termed as SBR. This force is to regard a bundle of transmitted rays that can or cannot reach the receiver's end.

The ray-tracing code consists of three sections such as:

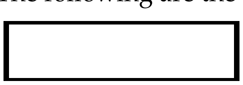
1. Input file parser
2. Construction of Ray diagram and
3. Computation of received field.

A simple ray shooting MATLAB package is applied for the research [20].

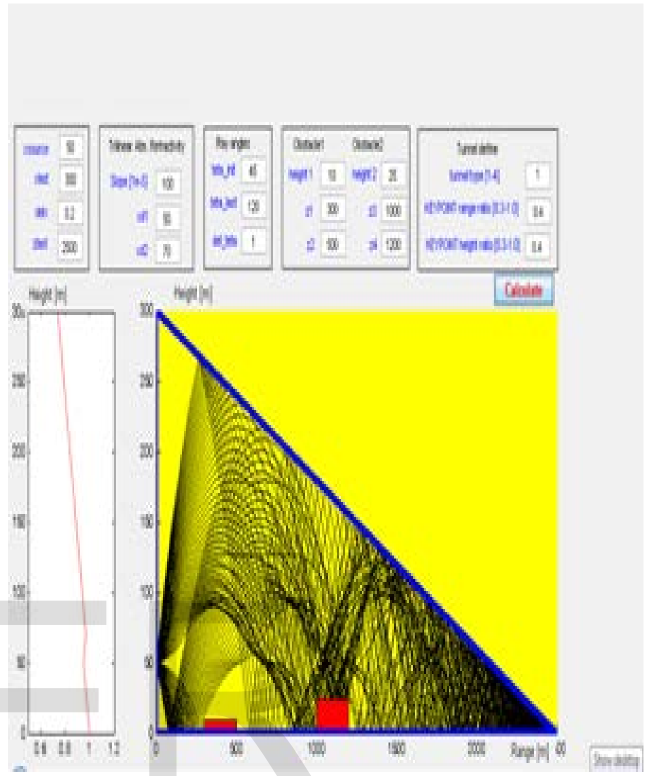
## 6 THE FOLLOWING ARE THE RESULTS OF VARIOUS SHAPES OF TUNNEL CONFIGURATIONS WITH WHICH MIMO WAS PROPAGATED

### 6.1 Tunnel 1

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



Z1= 300
Z2= 500

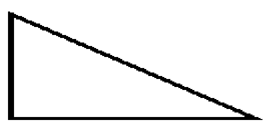


Z3= 1000
Z4=1200

The following is the ray diagram shot for the first tunnel

Fig 5: Ray diagram of tunnel 1

### 6.2 Tunnel 2



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

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

The following is the ray diagram shot for the second tunnel

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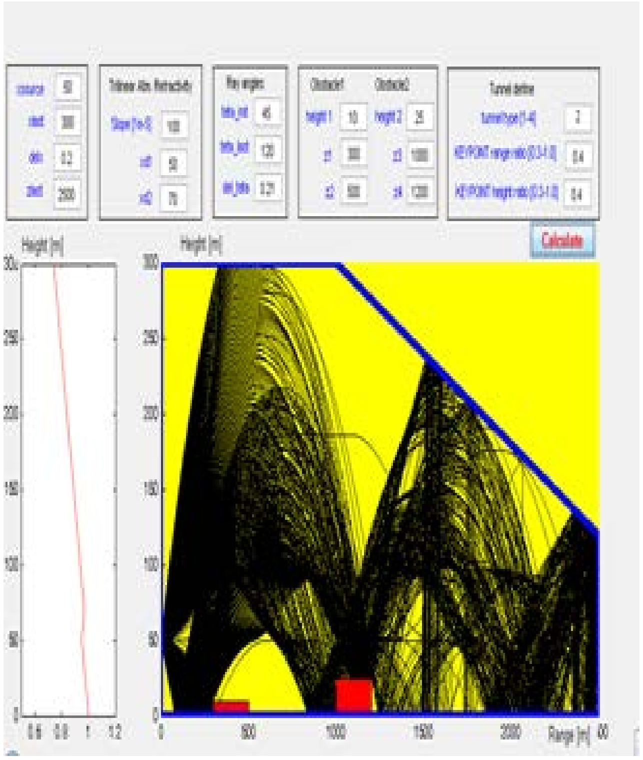
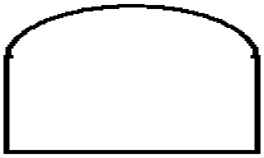


Fig 6: Ray diagram of tunnel 2

### 6.3 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.

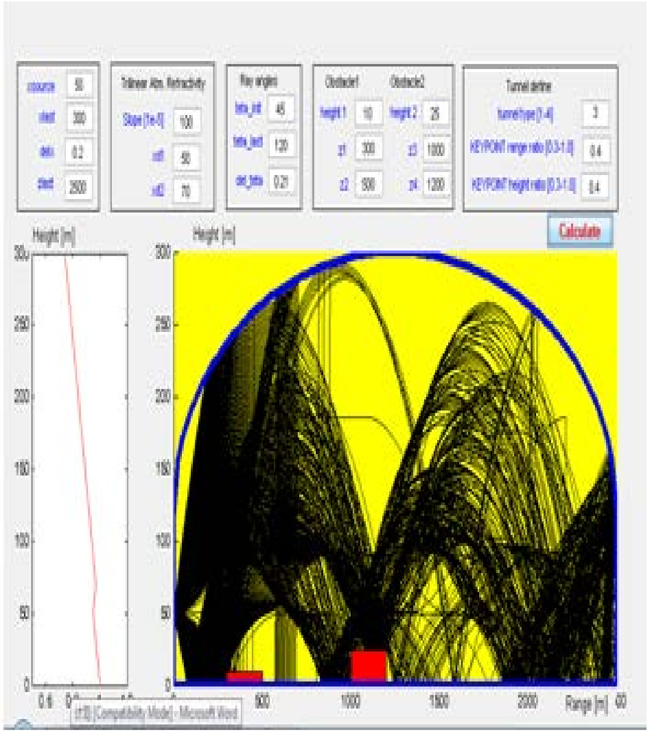
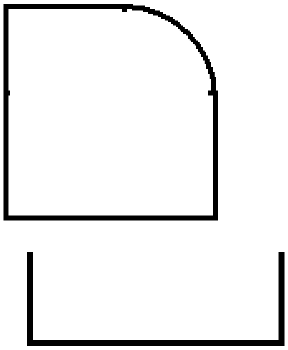


Figure 7: Ray diagram of tunnel 3



### 6.4 Tunnel 4

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

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

The following is the ray diagram shot for the fourth tunnel

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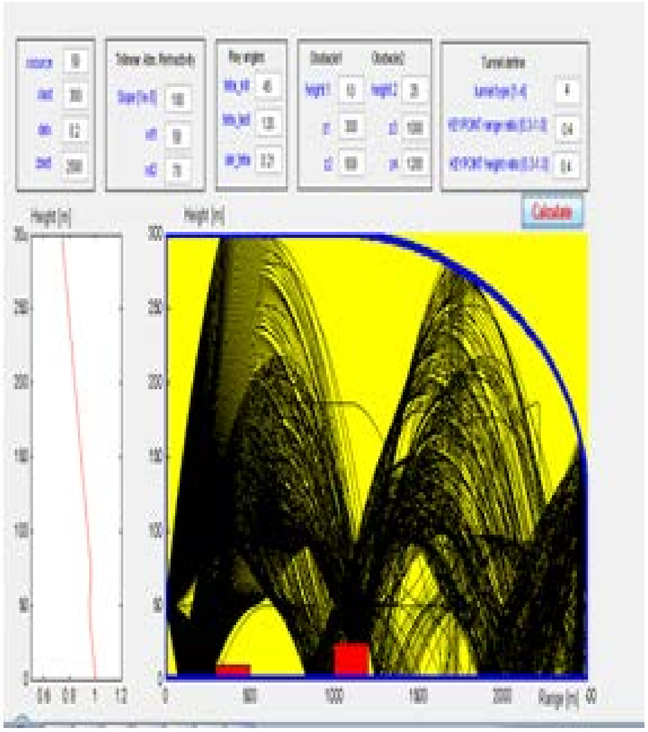


Fig 8: Ray diagram of tunnel 4

## 7 Conclusion

Today MIMO channel models are widely being propagated on tunnels and applied in several real time environments such as mines, railway tracks, subways etc for various data transmission purposes through digital communication systems. This study stands as an eye opener by setting a benchmark for the future applications of propagation of digital data through tunnels in real-time.

## 8 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.

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