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# PROPAGATION MODELS FOR V2V COMMUNICATION IN VEHICULAR AD-HOC NETWORKS

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**ABSTRACT**

There is lot of research work going in the area of vehicular ad-hoc networks (VANETs). Because these systems often comprise several tens, hundreds or even thousands of vehicle nodes, a real world test is very costly and time consuming operation. Vehicular Ad-hoc Networks (VANETs) research is carried out using different mobility and network simulators like MOVE, SUMO, TraNS, NS2 version 2.34 etc., because it allows for fast and cheap evaluation of protocols and applications in a controllable and reproducible manner. Simulation study helps us to use models in order to make a judgment on real-world problem viability. Models should reflect reality using radio propagation model for vehicle-to-vehicle communication, hence accuracy is an important requirement for propagation models.

**Keywords:** *VANETs, V2V Communication, Propagation models, Simulations etc.*

## 1. INTRODUCTION

Intelligent Transportation System (ITS) applications are being defined to improve highway road traffic safety, efficiency and comfort. Many applications rely on communication provided by vehicular ad-hoc networks (VNAETs). In vehicle-to-vehicle (V2V) communication on highway road takes place between vehicle nodes which meet by chance. A VANET occurs as soon as two or more vehicle nodes are within the communication distance/range.

No infrastructure is involved, vehicular ad-hoc networks (VANETs) rely heavily on distributed measures to regulate access to wireless channel. Protocols for random access, TDMA (Time Division Multiple Access) and flooding are implemented and evaluated in simulators. How well such a protocol will fare once deployed in a real-world test bed may differ greatly from the simulation results [1], as the simulator may be overly optimistic [2]. Reality provides opportunities for two vehicle nodes to exchange information which would not have been possible in simulator due to a simplistic propagation model [3].

Radio propagation model also has a strong impact on the performance of a protocol [4] because the propagation model determines the number of vehicle nodes within one collision domain, an important input for contention and interference. This has a direct effect on a vehicle node's ability to transmit a packet to another node, which can result in different values for metrics such as throughput, dropped packets, medium load and latency.

The mobility often involved in vehicular ad-hoc networks (VANETs) cause's vehicle nodes to move in and out of each other's transmission range. Depending on the radio propagation model a vehicle node may share a collision domain with tens or hundreds of other vehicle nodes, or with only a handful because the model accounts for buildings [5]. This paper provides the different propagation models which can be used in vehicular ad-hoc networks (VANETs) research, specifically in simulation studies.

## 2. SIMULATION

Network simulator i.e. NS2 is used in Vehicular Ad-hoc Networks research often provides a stack of protocols on top of which the protocol or application under test is implemented. A component with possible connections between vehicle nodes often works in conjunction with the propagation model in order to evaluate which vehicle nodes are affected by a transmission. Results could be a node correctly receives a message or receives garbled bits due to a collision.

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Mobility simulators i.e. MOVE, SUMO can be used to move the vehicle nodes on highway roads – as in generally the case in a VANET – either based on measured or generated traffic traces [6], an embedded mobility model [7,8] or a coupling with traffic simulation tool [9,10].

A simulation can have two goals:- 1) Perform a statistical exploration to gain insight in how a system will work in a generic environment, or 2) Perform a site-specific evaluation of a system to gain insight in the operational properties in a specific environment.

## 1.1 Mobility

VANETs are subset of Mobile Ad-hoc Networks (MANETs) with several differences between them. Mobility is usually constrained, because the vehicle nodes follow highway roads according to some physical vehicle model. Speed is generally high in VANETs, but can differ greatly, e.g. V2V communication between stopped vehicle nodes or vehicle nodes passing in opposite lanes. Vehicle nodes in a vehicular ad-hoc network generally do not have strict weight, size and power consumption limits. VANET nodes can safely be assumed to have access to certain peripherals such as positioning and navigation hardware.

Another important difference is a vehicle may easily travel outside an area covered by a certain legislature. Vehicles from multiple vendors will need to be able to cooperate; such standardization is an important accepts which is generally not considered when evaluating a MANET application.

## 1.2 Propagation Environment

The wireless channel is a highly chaotic and unpredictable system [3]. It's a way from transmitter to receiver a signal is being reflected, scattered and absorbed by the objects in the propagation environment. As such its magnitude is altered, but due to multiple paths it can also interfere with itself or with signals sent in other frequency ranges.

With context of VANET's comes also a typical radio wave propagation environment. Vehicles generally move on roads, but other scenery can vary from open farmlands to forests to large urban canyons and bridges. VANET propagation environment is the presence of large metal objects which are continuously changing position in the environment, namely the vehicles themselves, such environment is highly dynamic.

### 1.2.1 Large-scale effects

Large-scale effects on radio wave propagation are the following three phenomena:-

1) Reflection: It occurs when a wave encounters a large surface with certain optical properties. In models reflection is often translated to a path loss exponent, such as the 2 in (2) and 4 in Eq. (3)

2) Diffraction: This phenomenon is explained by Huygens Principle, which states that every point on a wave front acts as the seed for a secondary wave front. This enables waves to propagate around edges or through holes. This can be modeled with the knife-edge diffraction model [11], which can be used for site-specific modeling of propagation over mountains and large buildings.

3) Scattering: A radio wave scatters when it encounters an object which is small compared to the wavelength, spreading the waves in all directions. This can account for a received signal which is stronger than would have been predicted by reflection and diffraction alone.

### 1.2.2 Small-scale effects

Small-scale effects on radio wave propagation are often referred to as fading. At the receiver multiple versions of the original signal arrive; they can be reflected and diffracted and arrive with time and phase difference. These multipath waves interfere with each other, which can cause large fluctuations in signal quality with apparently small changes in time or receiver location. This relative motion causes frequency modulation because each multipath will have a different Doppler Shift; the resulting frequency change is derived as follows:

$$f_d = \frac{v}{\lambda}\cos\theta \qquad (1)$$

Here v is the relative velocity, λ the wavelength and θ the angle between the signal path and the direction of movement.

## 1.3 Channel Parameters

Mobile channel can be characterized with channel parameters. The reception of multipath components can be seen as a sample which can be expressed by means of statistical quantities. Delay Spread is the standard deviation of the arrival times. Doppler Spread measures the spectral broadcasting caused by relative motion of transmitter and receiver.

## 1.4 Radio Technologies

Many communication technologies are used in VANETs, such as infrared [12] and short range radio. Short range radio technologies used is Wi-Fi,

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but some research has done in 900MHz band [13] and in the millimeter range (60-78Hz) [14]. VANET research converges to IEEE 802.11p [15], a Wi-Fi used for communication in the vehicular environment part of the Wireless Access in Vehicular Environments (WAVE) standard [16], [17].

IEEE 802.11p builds upon the proven and mature 802.11 standards, providing relatively cheap but powerful and communication devices. It provides low latency access to the medium - nodes do not first have to associate and authenticate with base stations - and is optimized for the ad hoc domain. IEEE 802.11p operates on 7 channels in the 5.8-5.9GHz band (as shown in Figure.1) [18] and is expected to have a maximum communication range in the order of 1km.

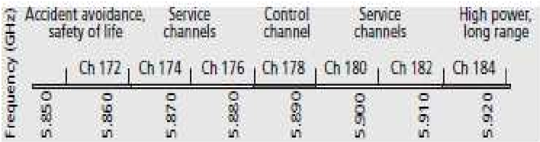

*Figure.1:WAVE Channel Assignments*

A node listens to the Control Channel (CCH) at least a certain amount of time. On the CCH announcements for services can be transmitted, these services can then be provided on the Service Channels (SCH). The WAVE standard does not define if one radio should listen to channels in time slots or if multiple radios can be used to observe several channels simultaneously. The channel access is defined in IEEE 1609.4 [19]. So far, most ITS-related VANET research focuses on applications operating on a single channel as if in isolation.

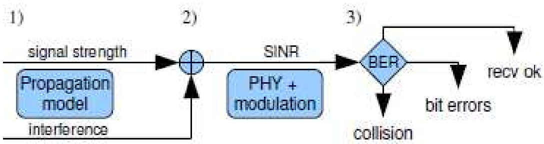

*Figure.2: Generic Model To Evaluate Reception*

### 1.5 Signal Parameters

The frequency at which a radio technology operates greatly impacts its propagation properties. Besides its carrier frequency, other metrics are the transmitted power, the bandwidth and the symbol time, these are results of the modulation scheme, a combination of signal and channel parameters can lead to different kinds of fading. This fading is often characterized by a probability distribution and appropriate parametric assumptions [20].

### 1.6 Implementation In Simulators

Implementation of propagation model in a simulator usually takes the following steps, illustrated in Figure.2:

1) For every node n within a relevant distance, perform a calculation of the received signal strength. The received signal strength is calculated using a propagation model.

2) For a transmission instance (e.g. the transmission of message x) all signal strengths from concurrent transmissions other than x received at node n are added as noise.

3) Based on the Signal-to-Interference and Noise Ratio (SINR) and Bit Error Rate (BER) a decision is made whether the message is correctly received or has bit errors. If the SINR is below a certain threshold it is impossible to detect the signal in the received noise, and a collision has occurred. Most propagation models in simulators consider nodes to be stationary for the duration of one transmission.

## 3. PROPAGATION MODELS

The propagation environment in the simulator is used to judge the effects of propagation of electro-magnetic waves through the medium, usually this medium is air.

In its most abstract form, this defines success or failure of reception of a message for a certain node. Propagation models can be classified in large scale and fading or small-scale models. From an implementation point of view they can be either deterministic or probabilistic.

### 3.1 Deterministic Models

A deterministic model allows computing the received signal strength, based on actual properties of the environment such as the distance between transmitters T and a receiver R. These models range from simple to very complex where they also account for multipath propagation in the environment modeled exactly as the area of deployment.

#### 3.1.1 Free space model

Which is sometimes also referred to as Friis model, after its inventor [21]? It models a single. Unobstructed communication path [20]. The received power depends only on the transmitted power, the antenna gain and the distance between the sender and the receiver, as shown in Figure. 3.a). As a radio wave travels away from an (Omni-directional) antenna, the power decreases with the square of the distance.

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$$P_r(d) = \frac{P_t G_t G_r \lambda^2}{(4\pi)^2 d^\alpha L} \quad (2)$$

Where $P_t$ is the transmitted power, $G_t$ and $G_r$ are the gains of the transmitter and receiver antenna gains and λ is the wavelength. α is the path loss exponent and is 2 in Free Space. L is the system loss. Often, $G_t$, $G_r$ and L are set to 1 from a topology point-of-view; this model regards the nodes as floating in free space.

### 3.1.2 Two-ray ground model

The two-ray ground model also accounts for a reflection via the ground, given the dielectric properties of the earth in addition to the direct line of sight (LOS). Nodes are positioned on a plane as depicted in Figure.3.b). This model gives more accurate predictions at longer range than the Free Space model [11] and is given as follows:

$$P_r(d) = \frac{P_t G_t G_r h_t^2 h_r^2}{d^4 L} \quad (3)$$

Where $h_t$ and $h_r$ are the heights (in meters) of the transmit and receive antennas respectively. Eq. (3) shows a faster power loss than (2), but does not give good results for short distances because of oscillation caused by the constructive and destructive combination of the two separate paths. Either (2) or (3) are used based on the magnitude of d, the T-R separation.

### 3.1.3 Ray tracing model

Ray tracing is a technique often used to predict propagation for cellular systems. Modeling the propagation environment plays a critical role in the development, planning and deployment of, for instance, UMTS/IMT2000 cellular systems [22]. Because for these systems not only coverage but also bandwidth is an important issue, careful site planning is in order. Ray tracing models can take into account the exact position, orientation and electrical properties of individual buildings in the environment in which the system is to function. Using the rules for reflection, diffraction and scattering all rays emanating from the source traveling towards a receiver can be modeled, as shown in Figure.3.c). As a result, a complex impulse response h(t) can be calculated as the sum of all contributions [23]:

$$h(t) = \sum_{n=1}^{N} A_n \delta(t - \tau_n) \exp(-j\upsilon_n) \quad (4)$$

The received signal h(t) has N time-delayed impulses (rays), each of which is an attenuated and phase-shifted version of the original transmitted signal. Amplitude $A_n$, arrival time $T_n$ and phase $\upsilon_n$ are calculated for each ray using Snell's laws, the uniform geometrical theory of diffraction (UTD) and Maxwell's equations. All objects in the environment need to be modeled with characteristics such as permittivity, conductivity and thickness. This method also allows to use antenna radiation patterns. Basically, ray tracing models are computed using 3-D vector mathematics. Evaluating every ray individually for a fixed antenna position is feasible, as it is used in cell planning. In VANET multiple transmitters and multiple receivers are moving in a continuously changing environment and h(t) will need to be recomputed upon a change in the environment. Ray tracing propagation models are not often used in VANET [24].

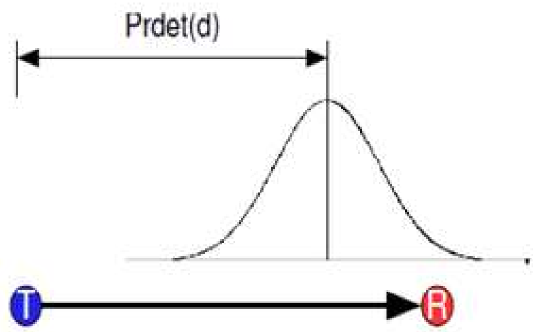


*Figure.4: Probabilistic Propagation.*

## 3.2 Probabilistic Models

Probabilistic models allow a more realistic modeling of radio wave propagation [3]. A probabilistic model takes a deterministic model as one as its input parameters in order to get a mean transmission range. For every individual transmission the received power is then drawn from a distribution, as shown in Fig. 4. The result is a more diverse distribution of successful receptions. It can happen with a certain probability that two nodes close to each other cannot communicate, although it can also happen with a certain probability that two nodes beyond the deterministic transmission range can communicate. The distribution of these effects depends on the probabilistic model and its parameters.

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#### 3.2.1 Log-normal shadowing

The Log-Normal Shadowing model uses a normal distribution with variance σ to distribute reception power in the logarithmic domain:

$$P_r = (d;\sigma^2) \sim LN(P_{r_{\det}}(d),\sigma^2) \quad (5)$$

Where $P_{r_{\det}}$ is a deterministic model such as Equation (.2) or (3). As such the received power is given as:

$$P_r(d) = P_t - \overline{PL}(d_o) + 10\alpha \log\left(\frac{d}{d_o}\right) + X_\sigma \quad (6)$$

Here α is a path loss exponent like the 2 in Equation (2) and the 4 in Equation (3). $\overline{PL}(d_o)$ is a reference path loss measured close to the transmitter. Equation (6) can be rewritten as

$$P_r = P_{r_{\det}}(d_o) \times 10^{PL(d)} \quad (7)$$

Which gives a received power by multiplying the deterministic received power with a Power Loss scale factor in dB?

$$PL(d) = -10\alpha \log 10\left(\frac{d}{d_o}\right) + X_\sigma \quad (8)$$

#### 3.2.2 Rayleigh

The Rayleigh propagation model [11] models the situation when there is no LOS, and only multipath components exist. This model incorporates intensive variations in received signal power because multiple paths can either combine constructively or destructively. The amplitude, delay and phase shift of these components greatly depends on the environment.

Like the Log-Normal shadowing model in Equation (5), the Rayleigh model also depends on a deterministic model to which a certain variation is applied:

$$P_{r_{Rayleih}}(d) \sim Rayleigh(P_{r_{\det}}(d)) \quad (9)$$

This can be rewritten to read:

$$P_r(d) = P_{r_{\det}}(d_o) \times 10^{PL(d)} \times \log(1 - unif(0,1)) \quad (10)$$

Where the Power Loss factor is defined by:

$$PL(d) = -\alpha \log 10\left(\frac{d}{d_o}\right) \quad (11)$$

#### 3.2.3 Longley-rice

The Longley-Rice model (or Rice model) [3] models the reception powers following the Rayleigh distribution but additionally takes into account the positive effects of a LOS path with a certain scale factor k [25]:

$$P_r(d) = P_{r_{\det}}(d_o) \times 10^{PL(d)} \quad (12)$$

$$P_{r_{Rice}}(d) = P_r(d) \times F(d) \quad (13)$$

With PL(d) as given in Equation (11) and F(d) defined as a Ricean PDF with a normal distribution:

$$F(d) = c(N(\sqrt{P_r(d)},1) + \sqrt{2k})^2 + N(\sqrt{P_r(d)},1)^2 \quad (14)$$

With c defined as $\frac{1}{2(k+1)}$.

#### 3.2.4 Nakagami

The Nakagami model is highly generic. Reception power follows a gamma distribution:

$$P_r(d;m) \sim Gamma\left(m, \frac{P_{r_{\det}}(d)}{m}\right) \quad (15)$$

The parameter m specifies the intensity of fading effects. Nakagami includes other models, such as:

~Rayleigh for m=1

~Free space for $\lim_{m \to \infty},$

Yet it is probabilistic [26]. This model has been proven to reflect certain environmental conditions and the consequences on reception power.

## 4. SIMULATION RESULTS

To find the propagation model that best characterize VANETs' channel, two kinds of

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simulations are conducted, one by using Network simulator ns-2.34.

### 4.1 NS2 simulation

The network simulator ns2.34 is used, which is a well known simulator in both academic and industrial fields in simulating and analyzing VANET's environment. The simulator has been extended to model VANETs by utilizing the IEEE 802.11p technology. The simulated network is mapped as circular bidirectional highway with a diameter of 2000*m* (6283*m* length) with 4 lanes in each direction. There are 600 vehicles on this highway segment and all of them equipped with DSRC and GPS technologies. The vehicles' speed ranges from 70 to 120*Km/h* and their movements follow a microscopic mobility model where the instantaneous speed is influenced by front vehicle's speed and has to change lane if it decides to bypass another vehicle. Each vehicle is configured to broadcast a status message of size 250*Bytes* periodically and all vehicles within its range are possible recipients. All configuration parameters are listed in Table.1. At the end we compare and analyze the different propagation models based on the packet delivery ratio and the time delay in receiving an emergency message.

In the first simulation scenario, only one vehicle is broadcasting its status message; all other vehicles are potential recipients. We are interested in the successful ratio of the received messages at different distances from the transmitter.

For the Shadowing propagation model, we used 2.8 as the path loss exponent and 4 as a standard deviation as specified in [27] for the highway scenario. For the Nakagami propagation model, we used the parameters specified by [28]. Figure.5 shows the packet successful reception rate versus distance. It is obvious that different propagation models give very different results for the same setup. This means that choosing the propagation model in any simulation setup is a main factor to judge on the validity of the results.

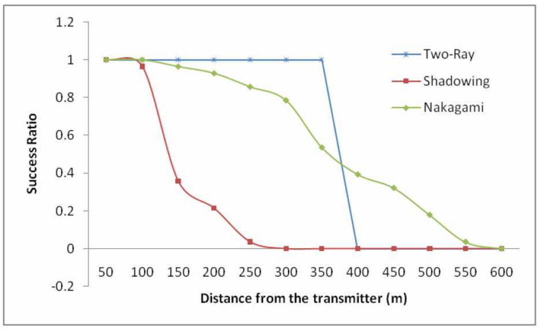


*Figure.5: The success ratio vs Distance*

In the second simulation scenario, we use the same parameters as in the first scenario except for two: the transmission power is increased to 0.002*W* and all vehicles are transmitting their status messages periodically. One vehicle is configured to send an emergency safety message to all behind vehicles. We are interested in the time till the warning message reaches a distance of 2000*m*. Figure.6 shows the time delay until the emergency message reaches the intended distance versus the status messages' sending rate (traffic load). It is obvious that the Two-Ray model suffers from high delay in a high traffic situation since all nodes within the range are competing to use the channel. While in the probabilistic models (Shadowing and Nakagami) not all nodes receive the signal successfully and so the number of nodes competing for the channel is less. It can be seen also that different propagation models give different results for the same scenario. This is a very serious issue in VANET especially in an accident situation where safety messages have to be propagated to all vehicles behind the accident in a short time. Using a simple model which assumes that all vehicles in the range receive the message successfully while in reality they are not, may result in fatal consequences.

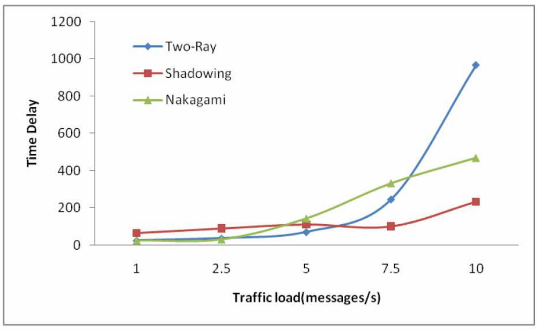


*Figure.6 Time delay vs Traffic load*

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*Table.1 Value Of Parameters Used In Simulation*

| Parameter | Value |
|---|---|
| Data rate of IEEE802.11p | 6Mbps |
| Message size | 250Bytes |
| Vehicles speed | 70-120km/h |
| Vehicles density | 12 cars/km/lane |
| Transmission power (Pt) | 0.001 |
| Received power threshold (RxThreshold) | 3.162e-12 |
| Carrier sense threshold (CSThreshold) | 3.162e-12 |
| Noise power threshold (Noise-floor) | 1.26e-13 |
| Height of the Tx and Rx antennas | 1.5 m |
| Gain of the Tx and Tr antennas (Gt=Gr) | 4 |

## 5. DISCUSSION

VANET is mostly modeled as a cluster of vehicle nodes on a highway road in a simulator. This can be accounted for by simply using a path loss exponent $\alpha \neq 2$ in the free space or two-ray ground model, depending on the environment and by changing other parameters such as deviation $\sigma$ when using a probabilistic model. When using the Nakagami or Rice model, the strength of a LOS component can be set with the m-parameter or the k-factor respectively.

Propagation model s used, it still needs to be parameterized correctly. In [30] the Log Normal Shadowing model was parameterized with $\alpha$=2.56 and $\sigma$=4 were used, based on real-world measurement data. In [26] a realistic set of parameters is provided for Nakagami model. Measurements performed at 900MHz [13] provided input for a set of parameters for the Rice model [31-33].

Model can be parameterized correctly; these parameters are averages of real-world data-mixing measurements of a highway. Choosing a set of parameters creates a homogenous propagation environment inside the simulator.

There is no VANET simulator which allows for sectorised propagation models, these scenarios could be simulated separately, but boundaries and transitions from one area to another may be of interest.

Deterministic models are often used in VANET research. They can greatly increase the runtime performance of a simulation but it is reasoned they describe real conditions insufficiently [3]. A probabilistic model could better account for the variance in real world situations, which enables vastly different communication between two vehicle nodes having the same T-R separation.

Another observation is that in VANET simulation, vehicle nodes themselves are often dimensionless. The vehicle nodes have no influence on radio propagation. It seems reasonable though, that in practice the large metal bodies of vehicles provide a wide range of effects on propagation:

- Vehicle nodes often block LOS between communicating vehicle nodes, making multipath components dominant.
- Vehicle nodes can function as waveguides or as reflectors, thereby increasing he transmission range beyond what could be expected based on free space propagation.

## 6. CONCLUSION AND FUTURE SCOPE

Propagation model used in vehicular ad-hoc networks simulation has large influence on the results. It impacts which nodes are able to communicate and the probability of correct reception range. It can influence the speed at which messages propagate through the network, directly influencing end-to-end delay in a multi-hop highway road scenario. The probability distribution of correct reception also influences the overhead with respect to collisions and medium utilization. The real-world implementation could behave different from the simulation, so care must be taken when mapping model and parameters to the target environment.

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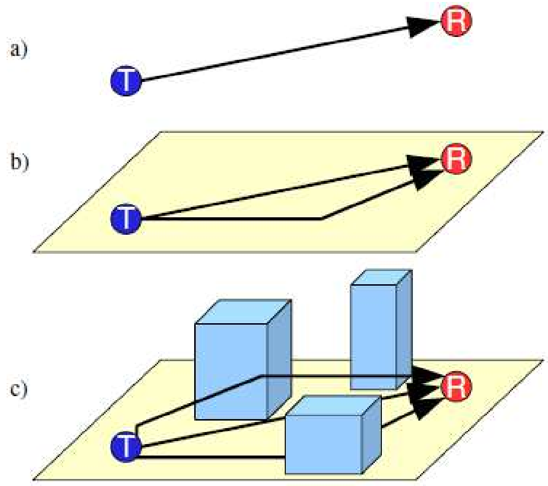


*FIGURE.3: DETERMINISTIC PROPAGATION: A) FREE SPACE, B)TWO-RAY GROUND , C)RAY TRACING.*