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Foreword

This Technical Report (TR) has been produced by ETSI Technical Committee Intelligent Transport Systems (ITS).

Modal verbs terminology

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1 Scope

The present document provides a set of channel models describing how signals in the 5,9 GHz frequency band are perturbed by the mobile radio environment in different use cases.

2 References

2.1 Normative references

Normative references are not applicable in the present document.

2.2 Informative references

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the referenced document (including any amendments) applies.

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3 Definition of terms, symbols and abbreviations

3.1 Terms

Void.

3.2 Symbols

For the purposes of the present document, the following symbols apply:

G_{RX}	Antenna Gain Receiver
G_{TX}	Antenna Gain Transmitter
K_{R}	Ricean K factor
L_{RC}	parameter denoting the number of random clusters
L_{RT}	parameter denoting the number of deterministic clusters

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AOA	Angle of Arrival
AOD	Angle of Departure
B2R	Base station to road side unit
C-ITS	Cooperative ITS
DUT	Device Under Test
ITS	Intelligent Transport Systems
LOS	Line-Of-Sight
LSP	Large-Scale-Parameters
MAC	Medium Access Control
MD	Mobile Discrete
MPC	MultiPath Component
NGSM	Non-Geometry Stochastic Model
NLOS	Non-LOS caused by objects other than vehicles
NLOSv	Non-LOS caused by vehicles
P2B	Pedestrian to base station
P2P	Pedestrian to pedestrian
PAS	Power angular spread
PDF	Probability Density Function
PL	Path Loss
R2R	Road side unit to road side unit
RMS	Root Mean Squared
RSU	Road side unit
RX	Receiver

SD	Static Discrete
SF	Shadow Fading
TDL	Tapped Delay Line
TX	Transmitter
US	Uncorrelated Scatterers
V2B	Vehicle to base station
V2I	Vehicle-to-Infrastructure
V2P	Vehicle to pedestrian
V2V	Vehicle-to-Vehicle
V2R	Vehicle to road side unit
V2X	Vehicle-to-X
VANET	Vehicular ad hoc networks
WSS	Wide Sense Stationary
XPR	Cross Polarization power Ratios
ZOA	Zenith angles Of Arrival
ZOD	Zenith angles Of Departure
ZSD	Zenith angle Spreads at Departure
GBDM	Geometry-based deterministic model
NS	Network Simulator
PHY	Physical Layer
FSPL	Free Space Path Loss
GBSCM	Geometry-based stochastic channel model
SLS	System Level Simulations
LLS	Link Level Simulations
DS	Delay Spread
ASA	Azimuth angle Spread of Arrival
ASD	Azimuth angle Spread of Departure
ZSA	Zenith angle Spread of Arrival
FIR	Finite Impuls Response
BS-UT	Base Station-User Terminal
GCS	Global Coordinate System
CDL	Cluster Delay Line
SCM	Stochastic Channel Model
NR	New Radio
UTD	Uniform Theory of Diffraction
TOA	Time Of Arrival
BS	Base Station
UT	User Terminal
LCS	Local Coordinate System
PDP	Probability Density Plot
WIM	WINNER Channel Model
WIM-SC	WIM-Spatial Consistency

4 Introduction

4.1 Wave propagation

Channel models, also called propagation models, are an important part when designing and evaluating wireless systems from the reception at the antenna all way up to the end user application. Channel models aim at mimic the perturbation signals undergo when travelling between transmitter (TX) and receiver (RX). The different effects that can be seen in a wireless channel are attenuation, reflection, transmission, diffraction, scattering, and wave guiding. The signal strength is decaying as the distance increases between TX and RX, i.e. the signal gets attenuated. Wave guiding is an effect that actually preserves the signal strength due to the fact that the signal is restricted in its expansion. It can occur for example in urban canyons and tunnels. In Figure 1, reflection, transmission, scattering, and diffraction, are illustrated. *Reflection* occurs on smooth surfaces, whereas *transmission* is when the signal penetrates the object. *Scattering* spreads the signal in several directions, which occurs on rough surfaces, and *diffraction* is when the signal is bending around a sharp edge. Smooth, rough, large, and small, are all relative to the wavelength in question. Increased carrier frequency implies smaller wavelength (e.g. 5,9 GHz is equal to a wavelength of 5 cm), more optical propagation, smaller antennas, and higher attenuation (the signal strength is decaying faster with distance).

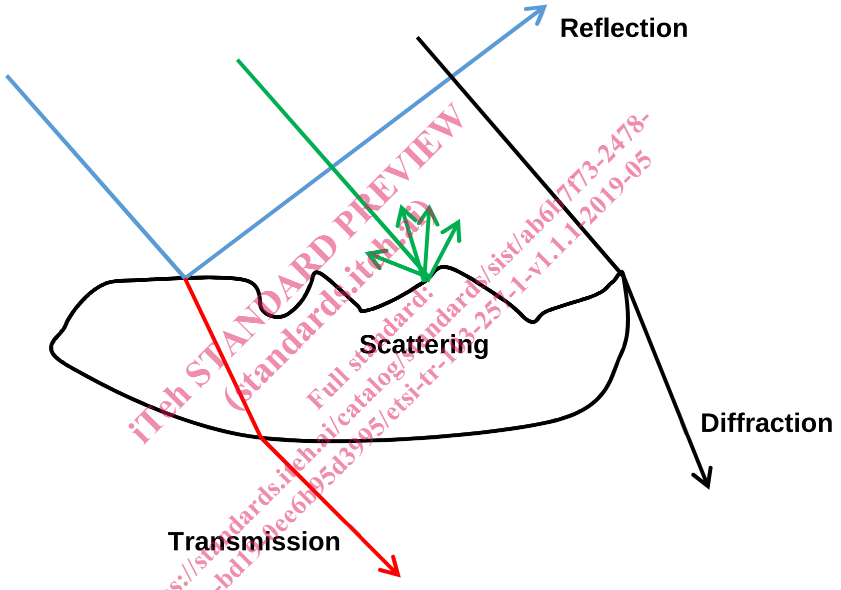

Figure 1: Different effects on the signal: transmission, reflection, scattering and diffraction

In wireless channels several replicas of the same signal can reach RX, which have bounced off different objects during propagation; and if TX and/or RX are moving there will be Doppler effects. This is relative movement of the TX/RX that shifts the frequency of the signal and makes it different at the receiver from the one that was originally transmitted. Figure 2 provides an example where RX receives one line-of-sight (LOS) component and two replicas of the signal that have bounced off objects (a multipath scenario).

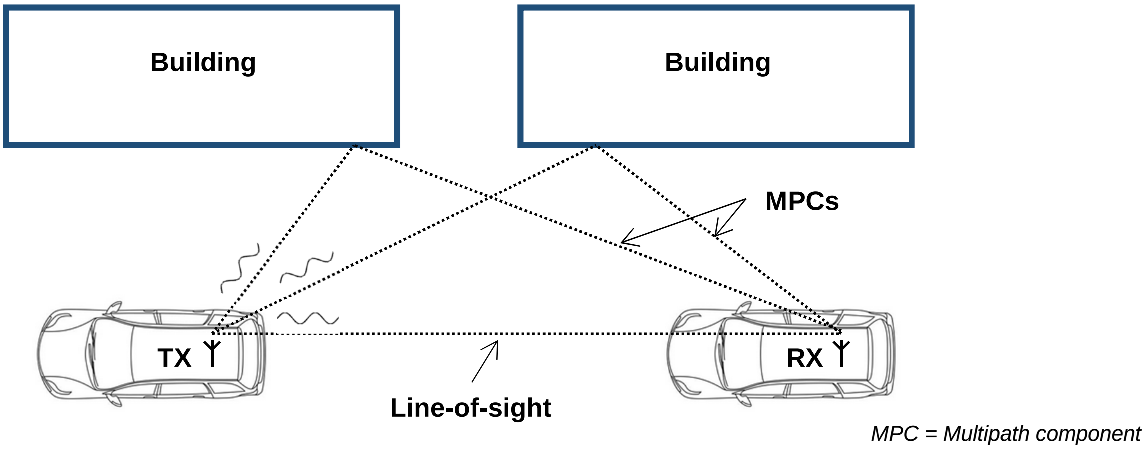

Figure 2: Multipath scenario, where several replicas of the signal besides the LOS component reach RX

The multipath components (MPC) will travel longer distances and will therefore arrive later than the LOS component. These delayed copies of the signal give rise to self-interference at RX, which could be constructive or destructive, see Figure 3. The worst case of destructive interference is when two equally strong signals are shifted 180 degrees (see Figure 3(b)).

(a) Constructive interference *(b) Destructive interference*

Figure 3: Constructive (a) and destructive self-interference (b)

4.2 Common channel models

There is a diverse set of channel models, which increase in complexity when more details about the propagation environment are added. The simplest channel models are deterministic path loss models, where the attenuation of the signal is based on a predetermined formula using the carrier frequency and distance between TX and RX as input. In other words, this kind of models will always result in the same result when the frequency and the distance is the same. Two well-known path loss models are the free-space path loss model and the two-ray ground reflection model. Free-space only assumes a LOS component, whereas the two-ray ground reflection model is consisting of one LOS component and one ground reflection (one MPC). There exist more advanced path loss models where parameters are derived from real-world channel measurements for the LOS as well as for the situation when the LOS is blocked by another vehicle or building.

A path loss model is always present regardless of how complex the channel model is, since this deterministically decides the signal strength based on TX-RX separation, carrier frequency, and possible obstruction of LOS component. Path loss models suitable for V2X communication are further detailed in clause 5.2.

Statistical models add a fading component to the path loss model. Fading is the fluctuation of the signal strength and it is often modelled as a random process. Fading could either be due to multipath propagation (a.k.a. small-scale fading) or shadowing from obstacles affecting the propagation (a.k.a. large-scale fading). Small-scale fading is due to multipath propagation effect as mentioned earlier (see Figure 2) and gives rise to a certain amount of either constructive or destructive self-interference (see Figure 3). If there is a LOS component, this is usually very dominant since this contains the most energy compared to other copies of the signal (MPCs). Large-scale fading captures fluctuations on a larger scale above 10 wavelengths as opposed to small-scale fading, which is within a wavelength.

Well-known statistical models for small-scale fading are Rayleigh, Rician, and Nakagami. In short, Rician distribution is used when the communication contains a LOS component and Rayleigh in absence of LOS. Nakagami captures both when there is a LOS and when this is absent. Nakagami is often used for protocol simulations of vehicular networks. Large-scale fading (shadowing) is very often represented by a Gaussian process.

In tapped delay line (TDL) models, individual MPCs are treated separately. Each MPC ("tap") will have its own fading statistics (e.g. Rician, Rayleigh) and phase shift, to cover phase differences between MPCs. Each tap may feature an individual Doppler spectrum. TDLs add better accuracy to the channel model by treating arriving MPC individually compared to when only using for example a Rician fading model (which could be regarded as only one signal hitting the RX). However, TDLs do not address the specific environment surrounding the vehicle such as buildings or objects that appear in different scenarios (however, a TDL could be tailored to a specific scenario).

TDLs and statistical models belong to the group of channel models that is called non-geometry based stochastic channel models (NGSM), which describe the paths between TX and RX by only statistical parameters without reference to the geometry.

Geometry-based stochastic channel models (GBSCM), on the other hand, also account for the environment such as buildings and vehicles, which are denoted scatterers. The geometry of the propagation environment is randomly generated according to specified statistical distributions. Dedicated vehicular radio channel measurements at 5 GHz show that the main contributions to the signal reception are LOS, deterministic scattering, and diffuse scattering components. The LOS component has high gain as long as there is a direct path from TX to RX. The LOS component's gain decreases whenever an interacting object obstructs the direct path (shadowing). The diffuse scattering contribution, stemming from surrounding buildings, other structures along the road, or foliage, forms a fairly large fraction of the overall channel gain.

Geometry-based deterministic model (GBDM) uses pure ray tracing or ray launching to determine the channel's characteristics. It needs 2.5D or 3D building data to search for all possible paths from TX to RX to find transmissions, reflections, diffraction, and scattering objects. Its result is deterministic. Searching for propagation paths is complex and it is computationally expensive. The complexity increases dramatically with the order of transmission and reflection, i.e. the number of possible interactions with objects. With increasing frequency band (decreasing wave length) the accuracy and hence reliability of ray tracing or launching based models decrease since impacts from material parameterization and small object detail modelling becomes more pronounced. Therefore, it is not a good choice to use it for a general channel model. Anyway, its deterministic approach can be used to create/parameterize new channel models as an alternative to time consuming real-world measurement campaigns. However, ray tracing allows for investigation of critical situations in which a statistical approach is not sufficient.

Table 1 summarizes the mentioned channel models and what aspects of the channel impairments each class of models try to address.

Table 1: Summary and description of different channel models

Channel model	Path loss	Fading	Doppler	Environment	Description
Path loss	X				Path loss models are integral in all channel models describing the deterministic signal attenuation based on TX-RX distance and carrier frequency.
Statistical models	X	X			Adds a fading component (both small-scale and large-scale) to the path loss. Models only one received signal component.
TDL	X	X	X		Models several MPCs individually using statistics but can also add Doppler effects due to speed differences between TX and RX.
Geometry-based stochastic models	X	X	X	X	Addresses also the environment by modelling potential scatterers according to statistical distributions which affect MPCs. Further, it addresses also the temporal evolution of the channel and thus considers correlations in time and space.
Geometry-based deterministic models	X	X	X	X	Addresses the whole propagation environment in a deterministic way by generating each MPC and its interaction with the environment (including for example material of buildings, street signs, foliage, etc.). Very scenario specific and computational expensive.

4.3 Usage of channel models

A channel model is selected based on what part of the communication system that is going to be studied. For network level simulations, where communication protocols including medium access control (MAC) are studied, a statistical model (e.g. Rician, Rayleigh, and Nakagami) is the predominant channel model type to keep computational time down. These simulations usually consist of many vehicles to stress the network and protocols and to find weaknesses of the system as a whole. Well-known network simulators for vehicular ad hoc networks (VANET) are NS-2, NS-3, Veins, OMNET++, and OPNET. Statistical channel models found in the literature for VANETs are parameterized for specific scenarios such as urban and highway.

For physical (PHY) layer simulations more details about the channel is necessary to understand how a certain PHY is affected by for example delay and Doppler spreads due to multipath propagation. More details about the scenario itself needs to be present in PHY layer simulations. TDLs and geometry-based stochastic and deterministic channel models are for obvious reasons the preferred channel models for this kind of simulations.

4.4 The 5,9 GHz frequency band and V2X communication

The 5,9 GHz band is a challenging frequency band for vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, collectively known as V2X communication, due to the high carrier frequency resulting in a wavelength of 5 cm. This frequency band provides a rich multipath environment especially in urban areas (many MPCs will arrive at RX). The LOS will often be blocked by other vehicles or buildings since the antennas are approximately on the same height especially in the V2V case. This results in many scatterers (both static and mobile) affecting the wave propagation especially in urban scenarios. Further, in highway scenarios high relative speeds can be achieved resulting in high Doppler. For communication with smart infrastructure (V2I), one node might be stationary and the antenna might be elevated resulting in a slightly better reception environment for moving vehicles but this is totally dependent on what kind of smart infrastructure that has been V2X enabled. The propagation channel for V2X is difficult to resemble due to the rich multipath environment.

4.5 Scenarios

4.5.1 Introduction

The selected V2X scenario has a major impact on the wave propagation and thus the channel model. There are three major scenarios: *urban*, *rural*, and *highway*, with the special case of tunnels. As the vehicle density increases in the different scenarios, the probability for the blockage of the LOS component increases and then strong MPCs needs to contribute to a successful reception of a transmission. Good reflectors are street signs and scatterers that are made of metallic structures with a smooth surface. However, good reflectors that are too far away can also cause a large delay spread resulting in inter-symbol interference and decoding problems when LOS is blocked. Delay spread is the delay between the first signal component arriving at the receiver and the last for a given symbol that is transmitted. Higher vehicle speeds can result in Doppler effect. In Figure 4, the scenarios detailed in subsequent clauses are illustrated.

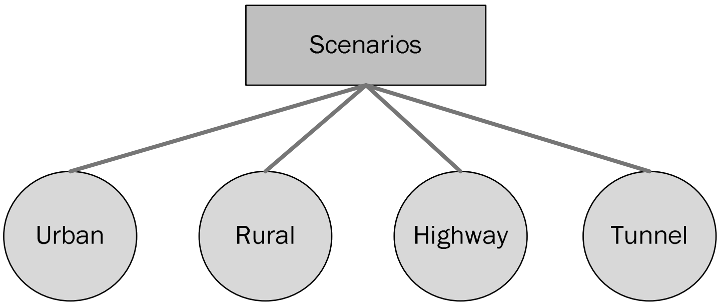

Figure 4: V2X scenarios