Modeling and Simulation of Land Mobile Satellite Channel Characteristics at S Band for DVB-SH Applications

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***Abstract*: Land Mobile satellite(LMS) channel characteristics at S band is modeled and simulated using markov state oriented statistical, physical-statistical and geometry based stochastic methods. Statistical models describe the channel in terms of statistical distributions. A Muli Input Multi Output (MIMO)(2_2) wideband Land Mobile Satellite channel is modeled using geometry based stochastic approach. A Single Input Single Output (SISO) narrowband Land Mobile Satellite channel is modeled using statistical and physical-statistical approaches. The parameters of these statistical models are extracted from measurement campaigns. In statistical land mobile satellite channel, shadowing and cause significant degradation on the received signal. Shadowing is modelled using lognormal distribution and multipath is modeled using Rayleigh distribution. Three state markov and two state semi-markov models are used for modeling and simulation of land mobile satellite channel. In three state markov model, channel is assumed to vary among line of sight, moderate shadowing and deep shadowing conditions. The channel is assumed to follow Loo distribution with different parameters in each state, where parameters are derived from experimental dataset. Transitions between states is modeled using Markov process. In two state semi-markov model, channel assumed to vary between good state and bad state. In good state, channel follows power law distribution where as in bad state channel follows lognormal distribution. Transition between states is modeled using semi-markov process. Parameters in two state semi-markov model follows Gaussian distribution. Compared to three state markov model, two state semi-markov model is more realistic. Physical-statistical models are combination of physical and statistical methods in which LOS (line of sight) component modeled using diffraction techniques and diffuse multipath component is modeled using distribution.**

Keywords*: MIMO, SISO, LMS, Markov, Loo, LOS, Statistical, Physical-Statistical Models, Geometry based Stochastic Process, Land Mobile Satellite

1. Introduction

Land mobile satellite channel modeling is at the interface between the _field of EM(Electromagnetic) wave propagation modeling and the field of signal processing applied to satellite broad casting, navigation and communication systems Although the modelling of electromagnetic wave propagation has been investigated since early nineteenth century with the emergence of wireless technologies, it had to wait for World War II to boost microwave applications and electromagnetic wave propagation modelling, especially for radar and communications purposes. Since then, electromagnetic wave propagation has experienced a spectacular growth and the demand for new wireless systems does not fall off. Nowadays, wireless mobile technologies are present everywhere. As an example, we can terrestrial mobile telecommunication systems (GSM, UMTS or LTE standards), indoor broadband systems (Wi-Fi a,b,g,n standards) and finally satellite-to-earth links (DVB-S or SDMB multimedia broadcasting standards). However, each of the mentioned wireless system is facing specific EM wave propagation impairments. Contrary to terrestrial and indoor EM propagation channels, satellite solutions are highly impacted by the atmosphere and the distance from the satellite. Satellite-to-earth links may suffer from low received power due to the distance, troposphere attenuation or depolarisation effects due to the Faraday rotation depending on the frequency of the link. Over the past twenty years and thanks to their huge cover area associated to reduced operating costs, satellites systems have first democratised voice and message transmission and more recently multimedia broadcasting and satellite navigation systems. From multimedia broadcasting to navigation applications, there are several main differences. The first one is their respective goal, maximum throughput for multimedia broadcasting and maximum synchronisation for navigation systems. To do so, the actual trend for multimedia broadcasting systems is to increase frequency up to Ka and Q/V bands to have access to wider bandwidth while satellite navigation systems use wider spreading codes for a more accurate synchronisation. The second main difference is the space segment where multimedia broadcasting systems mainly use unique GEO (Geostationary Earth Orbit) satellites while navigation systems uses MEO (Medium Earth Orbit) satellite constellations. It results in a different satellite motion from fixed to polar orbiting satellites with elevation and azimuth changes resulting in Doppler shifts as a side effect. One last main difference between both applications is due to the receiver motion: fixed or mobile. Fixed multimedia broadcasting systems mainly use fixed stations almost optimal propagation conditions are always achieved. However, for recent mobile broadcasting systems such as SDMB standard or for navigation purposes, the receiver is moving in complex environments where optimal propagation conditions are rarely fulfilled leading to shadowing, blockage, multipath fading, delayed echoes, Doppler spreading or depolarization issues .For economic reasons, satellite system evolutions are rare and operating margins are more and more reduced. This implies a strict control of many parameters impacting the whole system. To accurately design and maintain such complex systems, specific tools are to be created and integrated into system simulation chains where EM wave propagation is one among many other parameters impacting system performances. A typical Land Mobile Satellite scenario is shown in Fig. 1. A geostationary communication satellite serves the mobile user, the link either embodies line-of-sight (LOS) conditions or shadowed conditions on the direct path (blue arrow) and a combination of many constructively and destructively interfering multipath signals (green arrows), which are randomly delayed, affected by Doppler shifts, scattered, reflected, and diffracted. The combination of the direct line of Sight signal and the random (Rayleigh-distributed) multipath signals is taken as the Rician model. However, mainly due to the shadowed or non-shadowed direct path, the Land Mobile Satellite channel can no longer be described by a single distribution, thus the three state fontan model implements different distributions embraced by a first-order Markov chain

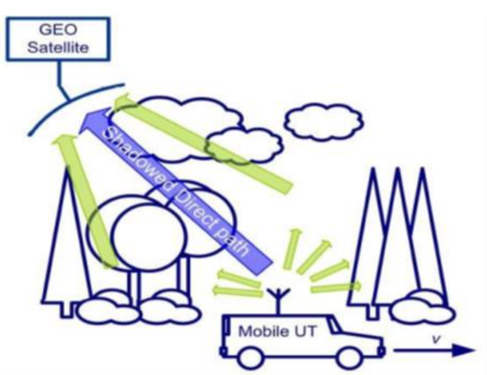

Fig. 1. Land Mobile Satellite Scenario

A. Differences in propagation characteristics between satellite and terrestrial channels

The only significant effects are those caused by the environment close to the user terminal as atmospheric effects are negligible for frequency below3 GHz. For DVB-SH (Digital video broadcasting satellite services to hand-held devices),three main mobile environments may be considered. They are

- *Rural environment:* The propagation is mainly affected by the vegetation. The coverage is mainly provided by the satellite component
- *Urban environment:* The propagation is mostly affected by dense buildings or other constructions with heightof4storeysor more. The coverage is mainly provided by the complementary ground component •Suburban environment: Representing an intermediate case with medium density of buildings, lower structures (2 to 3 storeys)and roads which are wider than in an urban environment. The satellite component and the complementary ground component contribute to the desired coverage. Small villages may be treated as suburban areas where, if the population density is low, satellite may be the only source for service provision. For both land mobile satellite and terrestrial mobile channels, the effects are conventionally divided into three types according to the scale of distances to be considered: •Path loss at large scale (very slow fluctuations): The signal suffers variations due to modifications in the geometry of the propagation path. This loss is usually assumed to be proportional to dn, d being the distance from the transmitter to the user terminal land n being an empirical exponent, based on theory and measurements. For satellite channels n=2 while for terrestrial channels typically n=4;
- *Shadowing at mid-scale (slow fluctuations):* It corresponds to amplitude variations due to nearby obstacles on the ground. The signal suffers variations due to obstructions caused by buildings, trees etc., the scale here being similar to the dimensions of these obstacles
- *Multipath fading at small scale (fast fluctuations):* The scale of the variations of the signal is about one wavelength, as a result of the constructive or destructive addition of multiple paths. For wide band systems, it is necessary to consider the multipath fading as frequency selective. The satellite propagation

B. Motivation

Channel modeling is the characterization of the land mobile satellite channel, it describes how the characteristics of the sent signal can be affected or what the conditions of the environment are, i.e. frequency, obstacles in the path, etc. The channel model helps to evaluate the performance of the system and to compare different techniques to mitigate the perturbations so the best fitted solution can be implemented according to the presented problem.

2. Literature review

A. Classification of channel Models

The land mobile satellite channel models can be grouped into three classes. Those are empirical, statistical, physical models. Empirical models are obtained from experimental data. They are very close to reality for the environment type in which the measurements have been done but are difficult to generalize to other environment types. Statistical models are based on the use of canonical statistical distributions. Like empirical models, statistical models are applied to environment classes (rural, suburban, urban, etc.). The subsequent classification problem is not straightforward, since an environment classified as urban in some .Therefore statistical models are also difficult to generalize. Physical models rely on a deterministic modelling of the propagation phenomena (reflection, diffraction, refraction), but also of the considered environment. These models have been efficiently used for planning purposes in terrestrial radio-communication or broadcast networks

1) Single-state models

Statistical models for satellite channels make the assumption that the received signal is composed of two parts: a coherent part associated with the LOS path and a diffuse part arising from multipath components. The Rice model assumes that the LOS component is only affected by Rayleigh distributed multipath and is characterized by the carrier-to-multipath ratio (C/Mor Rice factor K). The Loo model assumes that the LOS is affected by lognormal shadowing (typical for tree shadowing) which makes the instantaneous C/M time variant. The Corazza model assumes that both the LOS and the multipath components are affected by the same lognormal shadowing. Thus in the Corazza model the C/M is constant all though both the LOS and the average multipath power components are lognormal distributed. The Hwang model also considers lognormal process affecting both the LOS and the multipath component but with total decorrelation between them. The Hwang Model has been shown to include the Rice, Looand Corazza models as special cases. As DVB-SH is supposed to operate in different mobile environments, where channel conditions are time variant, a single-state channel model is considered in adequate.

2) Two-state (Lutz) model

The Lutz model is a statistical model which represents the channel by a two states Markov chain. The good state occurs when a dominant line-of-sight component is received. In that state, the channel can be considered as a Rician channel. The bad state occurs when no LOS component is received. In this state, the channel can be modelled as a Log-normal Rayleigh channel without coherent component. The parameters associated with each state and the transition probabilities from one state to another are empirically derived. This approach allows the generation of time series representing different environments. However, two-state channels were considered not enough to represent the variety of propagation conditions experienced in the different environments.

B. Three-state (Fontan) Model

A further refinement of the Lutz model is represented by the Fontan model which includes a three-state Markov chain

- State 1: Line of Sight (LOS)
- State 2: Moderate shadowing
- State 3: Deep shadowing

The statistical model adopted for all three states is a Rice/lognormal distribution with parameters that have been experimentally derived from propagation campaigns Performed in different European locations. The model parameters are reported in for different environments, elevation angles and locations. Being recognized as the most accurate statistical LMS channel model available today, encompassing the widest set of environments and elevation angles, this model has been adopted for the DVB -SH performance evaluation.

3. Statistical modelling of land mobile satellite channel

A. Markov process

One type of stochastic process is Markov chains, named after Andrei Markov who studied the transitions between consonants and vowels in a poem. In this process, a set is defined as X(t), t = 0, 1, 2, ... whose number of elements is finite and denoted with real positive numbers. X(t) =i represents that the process is in state I at an instant of time t and take discrete values. It is said that there is a fixed probability p_{ij} that chain goes from a state i to a state j in the next time t. This process is represented in and it is known as the Markov property P [X (t*k*+1) = x*k*+1|X(t*k* = x*k*, ., X(t1) = x1]= P [X(t*k*+1) = x*k*+1|X(t*k*) = x*k*] Where, X(t*k*), current sample. X (t*k*+1), future sample. X (t1)... X(tk − 1), past samples. x*k*, state of the sample in the moment k. Markov property indicates that given the present state, the next state is conditionally independent of the past.

B. Semi markov model

The enhanced two state semi-markov Model is an evolution of the three state fontan models. Among the modifications is the assumption of only two distinct macroscopic shadowing or blockage behaviours or states: the GOOD and the BAD (not necessarily matching line of sight and non-line of sight conditions) in lieu of three states: line-of-sight, intermediate shadow and heavy blocked. To compensate for this reduction in the number of states, a wide range of possible parameters, compared to the three state fontan model for which the parameters were constant. The enhanced two state model is figure 3.1 where the only two possible states are defined with one entire set of Loo distribution parameters (Loo-moderate-shadowing and Loo heavy-shadowing) assigned to each. The new model allows the Loo distributions corresponding to each of the two states to take up a different parameter triplet MA, A and MP with each state occurrence. To each state corresponds a parameter space where the parameters follow a given joint distribution. When performing simulations, each time a new state is reached, a Loo parameter triplet must be drawn.

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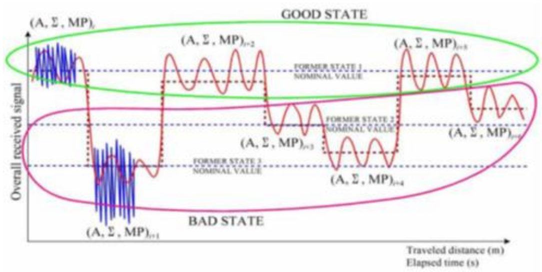

Fig. 2. Three-state model and two-state model

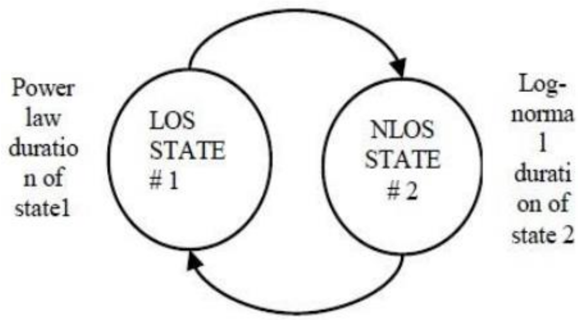

Fig. 3. Two State Semi-markov Process

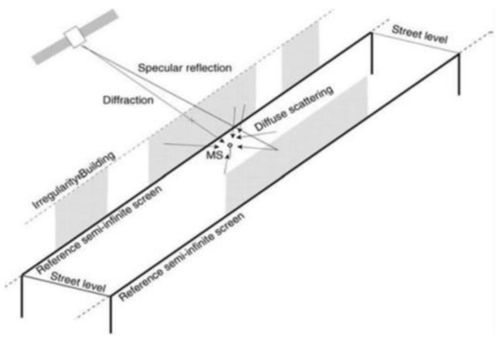

Fig. 4. Simulation scenario of physical-statistical Land mobile satellite channel

C. Physical Statistical Modelling of Land Mobile satellite Channel

The physical-statistical model is a narrow band model and assumes that the baseband equivalent complex envelope of received signal is the result of the coherent sum of two phasors rTexp(jφT)=rDexp(jφD)+rMexp(jφM) where subscript T indicates total or over all signal, indicates direct signal and M, diffuse multipath The path geometry is illustrated in Fig. 5. A mobile user is situated on along Straight Street with a direct ray from the satellite impinging on the mobile from an arbitrary direction. The received power from the direct path is given by scalar kirchoff diffraction equation.

In Fig. 4, buildings on the transmitter/satellite side of the street are represented as rectangular irregularities or protuberances on an infinite screen. The diffraction effects were computed by performing integration throughout the aperture defined from the screen infinite. The overall integration was split into smaller areas to ease the computation process. Modelling the gives the relationship between P and the free-space electric field.

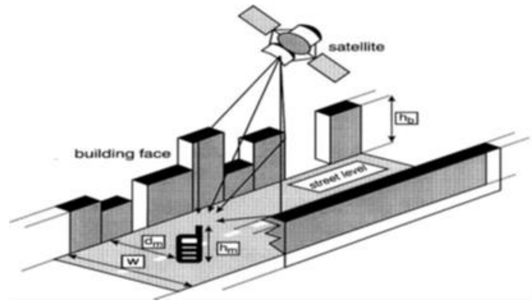

Fig. 5. Path Geometry for mobile satellite

Geometry based Stochastic Modeling of Land Mobile Satellite Channel: This Model Combines the advantages of deterministic and statistical Channel Modelling. A geometry based approach allows the emulation of antenna effects, whereas the propagation characteristics are described by statistical models. In geometry based stochastic model, the case of dual-polarized MIMO with circular l antennas plays an important role. By applying the correct geometries o the transmission system the distance-related effects are incorporated into the model. The satellite environment can be introduced by inserting directive transmission antennas into the model. In case of a GEO satellite, static values for distance, elevation, angular spread of departure (ASD) and elevation spread of departure (ESD) can be used.

4. Simulation and results

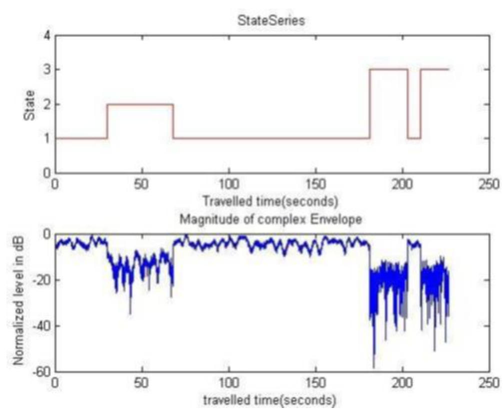

Fig. 6. Simulated Time series of Statistical Three state markov process

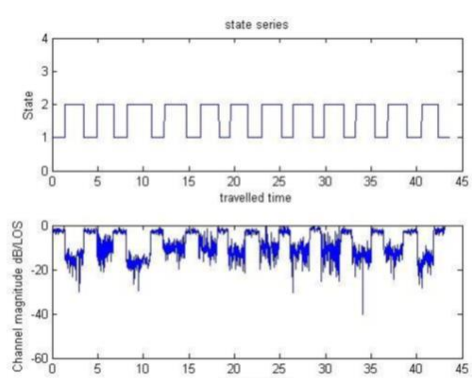

Fig. 7. Simulated Time Series of Statistical Two state semi-markov process

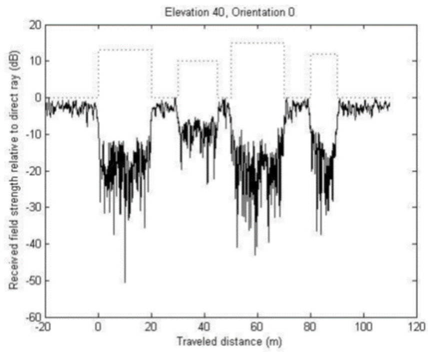

Fig. 8. Simulated Time Series of LMS Channel using Physical Statistical method

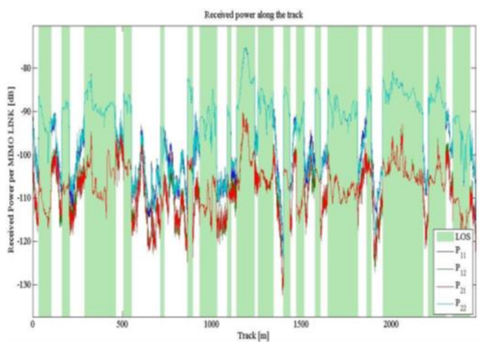

Fig. 9. Simulated Time series of LMS Channel using geometry based stochastic methods

5. Conclusion

Land mobile satellite channel is modelled using state oriented statistical, physical statistical and geometry based stochastic methods. In state oriented statistical methods environment is generated statistically and interaction with environment is also statistical. Statistical methods are computationally less complex but inaccurate. In physical-statistical methods, environment is generated statistically and interaction with environment is physical. Physical-statistical methods are accurate and computationally complex. In geometry based stochastic models, position of transmitter, receivers are defined geometrically and position of scatterers are defined stochastically, parameters are based on statistical distributions extracted from measurement campaigns. Among these three methods geometry based stochastic method is more realistic because it comprises angle of arrival, departure, and polarization and MIMO configuration.

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