Channel Modeling and Simulation in HAPS Systems

José Luis Cuevas-Ruíz
Signal Theory and Communications Department (TSC)
Universidad Politécnica de Cataluña
e-mail: jcuevas@tsc.upc.es

José A. Delgado-Penín
Signal Theory and Communications Department (TSC)
Universidad Politécnica de Cataluña
e-mail: delpen@tsc.upc.es

Abstract. Increase on the demand of telecommunication services is related with systems based on different technological alternatives. One of them, that is being developed in the last years is the use of aircrafts or airships technologies. The High Altitude Platforms Stations (HAPS) represent one attractive option today. In this paper, a switched channel model in L band based on HAPS is proposed and analyzed by simulation and several conditions related with the radio coverage and enviromental conditions are analyzed.

Index terms: HAPS, switched channel, semi-Markov process.

I.- INTRODUCTION.

This paper present a channel model for HAPS systems, and performance results evaluated by simulation are shown. In section II are given the principal characteristics of these systems. These platforms have a potential capability to serve a large number of users, situated over a terrestrial geographical area, using considerably less communications infrastructure that a terrestrial network. In section III is presented a brief introduction to the typical propagation enviroment of the HAPS, are considered a channel model based on semi-Markov process and distributions of fading for some diferents kinds of channels. The model propused is detailed in section IV, analyzing the system performance with two and three states and in section V the results obtained in the simulation are shown. Finally, some conclusions are exposed in section VI.

II.- HAPS (High Altitude Platforms).

A. *Systems based on HAPS.*

The systems based on HAPS represent a technological alternative that is being developed in last years; these systems could have many advantages of both terrestrial and satelital systems, while at the same time avording many of the pitfalls [1] [2]. The ITU-R, in the Recommendation F-1500 [3] defines the technical and operational characteristics for fixed services using HAPS.

The system comprises a High Altitude Platform in a nominally fixed location in the stratosphere at a height between 21 and 25 km. The communications are established between the platform and user terminals on the ground in a cellular arrangement. User terminals are described as being one of the three zones: Urban (UAC) for a 90 to 30º, Suburban (SAC) for a 30 to 15º and Rural (RAC) for a 15 to 5º and are defined in function of the elevation angle of the receiver

In a system based on HAPS, the communications between the platform and a number of gateways stations on the ground, located in the UAC or SAC area, provide interconexion with the fixed telecommunication networks (Figure No.1).

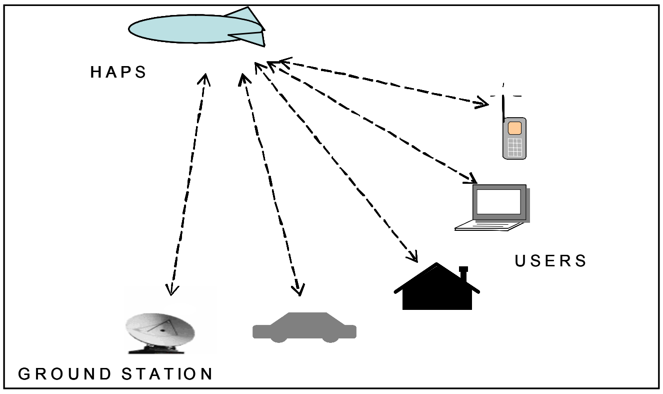


Figure No.1 System based on HAPS.

B.- *Probability density models for the signal fluctuations.*

The firts step toward developing a meaningful channel model is to identify typical scenarios. We will restric to the three more representative.

In an urban area there are a LOS condition and a difusse multipath component. The LOS condition is due to the relatively short distance of the platform; the difusse component consist of many reflections from the obtacles in the area, each of them being indenpendent and randomly phased. The envelope of this difusse signal is characterized by means of a Rayleigh probability distribution. The sum of a constant envelope and a Rayleigh distributed difusse signal results in an envelope Rice probability distributed [6], and is expresed by

$$p(r) = 2kre^{(-k(r^2+1))} I_0(2kr) \qquad (1)$$

where k is the Rice factor and I_0 denotes the zeroth-order modified Bessel function of the first kind; this Rice factor is calculated by

$$k = \frac{s^2}{2\sigma^2} \quad (2)$$

and is defined as the ratio between the average power of the direct component (LOS) and average power asociated to the multipaths.

In the suburban area, the obstacles near to the receiver cause a signal shadowing and an attenuation of the direct signal; due that some obstacles are moving (vehicles), the attenuation of the direct signal varies. The attenuation of the direct signal undergoes log-normal distribution [6].

$$p(s) = \frac{10}{\sqrt{2\pi}\,\ln(10)}\frac{1}{s}\exp\left(-\frac{(10\log s - \mu)^2}{2\sigma^2}\right) \quad (3)$$

where μ and σ are the mean value and the standar deviation expresed in dB.

III.- STATISTICAL CHANNEL MODEL.

A.- *Three state semi-Markov chain model.*

As the enviromentals properties change, the received signal cannot be represented by a model with constant parameters, then the channel must be modeled using a finite state Markov model. The transitions between states are determined by a matrix **P**, where each element P_{ij} represent the probability that the channel changes from the *i* to the *j* state. For the channel model with three states A, B and C, is defined the transitions matrix **P**

$$P = \begin{pmatrix} P_{AA} & P_{AB} & P_{AC} \\ P_{BA} & P_{BB} & P_{BC} \\ P_{CA} & P_{CB} & P_{CC} \end{pmatrix} \quad (4)$$

A stationary state vector **π** is calculated, using the properties of the Markov processes expressed by

$$\boldsymbol{\pi}(\mathbf{I}-\mathbf{P})=0 \quad (5)$$

$$\boldsymbol{\pi}\mathbf{e}=1 \quad (6)$$

where **I** is the identity matrix, **P** is the transition matrix and **e**= $[1\ 1\ \ldots]^T$ [7]. Each element π_i represent the percentage of the total time that the processes remains in the *i* state.

$$\boldsymbol{\pi} = (\pi_A\ \pi_B\ \pi_C) \quad (7)$$

A semi-Markov process is a Markov chain where the time between changes of states are random and defined for some kind of distribution [8]. From the Markov process, a new semi-Markovian process is defined. This process will be described by a new transition matrix **r** [8] , which is evaluated using

$$r_{ij} = \frac{Pij}{1-Pii} \quad para \quad r \neq j \quad y \quad r_{ii} = 0 \quad (8)$$

The scheme of the figure No. 2 shows a graphical representation of a semi-Markovian process.

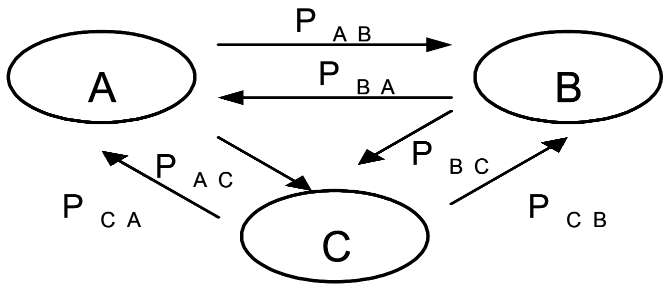


Figure No.2 Semi-Markovian Process.

B.- *Distribution of fades.*

Some distributions are described for fade duration in the ITU-R Recommendation P.681-6 [8]. In this Recommendation are defined three types of channel:

- A state. LOS condition.
- B state. Slight shadowing.
- C state. Total obstruction.

For the A state, the duration follows an exponencial distribution given by

$$P_A(D \leq d) = 1 - \beta d^{-\gamma} \quad (9)$$

where the parameters *β* and *γ* are function of the level of the shadowing and for $d > \beta^{1/\gamma}$. The duration for the others states follows a lognormal distribution valid for *d > 0.1 m*, and is expressed as

$$P_{B,C}(D \leq d) = (1 + erf[\ln(d) - \ln(\alpha)) / \sqrt{2\sigma}\,])/2 \quad (10)$$

where *σ* is the standard deviation of *ln(d),* the mean value of *ln(d)* is *ln(α)* and the error function is defined in the ITU-R Recommendation P.1057. The ITU-R Recommendation P.681 establishes the parameters for the duration for these states, and the distribution of the duration; these durations can be established in agreement with the characteristics of each state.

IV.- A CHANNEL SIMULATION MODEL FOR HAPS.

A.- *Two state semi-Markov chain.*

In this model is defined two types of channel: "*good*" and "*bad*" [6]; this is the most simple switching channel model and is useful for to compare the performance with channel models with more than two states; this model is similar to the present by Lutz [6], but in this case the distribution of the fading is diferent in each state, in agreement with [8]. The channel model implemented considers a switching between a Rice (*good channel*) and Rayleigh-Lognormal (*bad channel*) fading (Figure No.3).

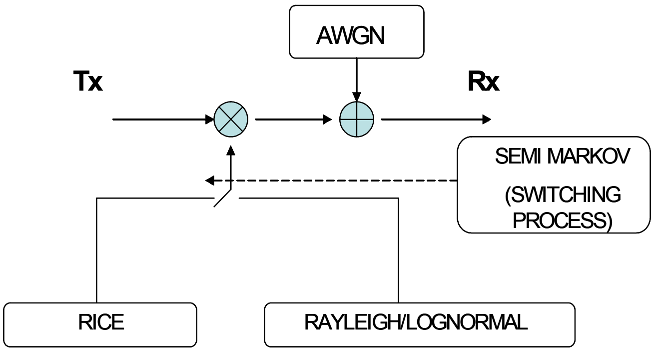


Figure No.3 Two states channel model

In [6] are reported distributions of fading for an Urban area; in the figures showed in [6] are indicated probabilities of the short-term mean values received power staying above o below a threshold for more than n bits durations. The threshold corresponds to the time-share of shadowing, A. The probabilities are normalized such that $P_g(>0)=1-A$ and $P_b(>0)=A$. These measurements were done in a City enviroment. Whit this information is posible to computed the matrix **P** applied a LMS aproximation and using the equations indicated in (12), that defines the time that a Markov chain remains in each state. The probability that a *good* or *bad* channel state lasts longer than n bits follows a geometric distribution and is given by

$$p_g(>n) = p_{gg}^n \qquad (12)$$
$$p_b(>n) = p_{bb}^n$$

For a probability of $P_b(>n)=10^{-3}$, (*for n=20000*) the probability P_{bb} is 0.9965467; in the same way is calculated P_{gg}= 0.9974. With this information and considering that the elements of the matrix **P** obeys the property indicated by (13)

$$\sum_{i=1}^{N} P_{ki} = 1; \qquad k = cte \qquad (13)$$

then the matrix **P** is fulfilled (14).

$$P = \begin{pmatrix} P_{gg} & P_{gb} \\ P_{bg} & P_{bb} \end{pmatrix} = \begin{pmatrix} 0.99735 & 2.65e-3 \\ 3.45e-3 & 0.99654 \end{pmatrix} \qquad (14)$$

and the stationary probability $\boldsymbol{\pi}$ can be computed from the matrix equations indicated en (5) and (6)

$$\boldsymbol{\pi} = (0.565 \;\; 0.434) \qquad (15)$$

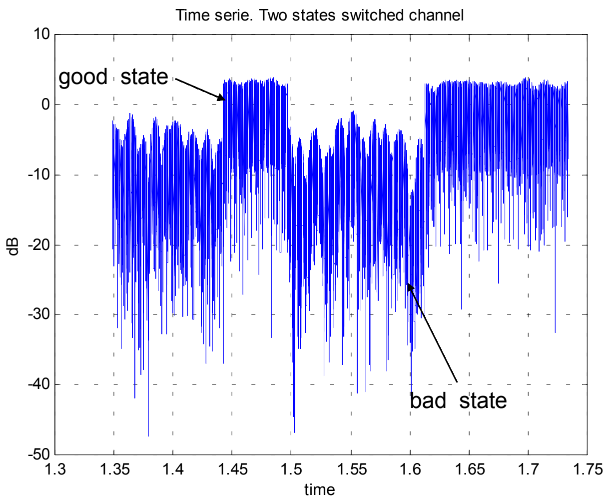
The time shared of shadowing A is related to the durations of each of the states, Dg and Db, and following to Lutz [6], it is defined as

$$A = \frac{D_b}{D_b + D_g} \qquad (16)$$

and the value computed is of 56.5%. The simulation was done using the semi-Markovian processes and therefore the process only present transitions between adjacent states and the durations of each channel state were determined in agree with [8]; thus, the matrix of the semi-Markovian process was defined as follows

$$r = \begin{pmatrix} 0 & 1 \\ 1 & 0 \end{pmatrix} \qquad (17)$$

In Fig No. 4 is represented the time series for a two state channel model; from these series is posible to calculate the mean value duration of each state, as well as to analyze the transitions between states for computing the transitions matrix



P.

Figure No.4 Time series for the two states channel model

B.- *Three states semi-Markov chain.*

TABLE No.1

		Enviroments		
	Parameters	Suburban I	Suburban II	Forest
A state	β	0.88	0.83	0.60
	γ	0.61	0.66	0.84
B state	α	1.73	1.89	2.05
	σ	1.11	0.93	1.05
C state	α	2.62	3.28	1.55
	σ	0.98	1.04	1.02
P	P_{AB}	1	1	1
	P_{AC}	0	0	0
	P_{BA}	0.65	0.65	0.42
	P_{BC}	0.35	0.35	0.58
	P_{CA}	0	0	0
	P_{CB}	1	1	1

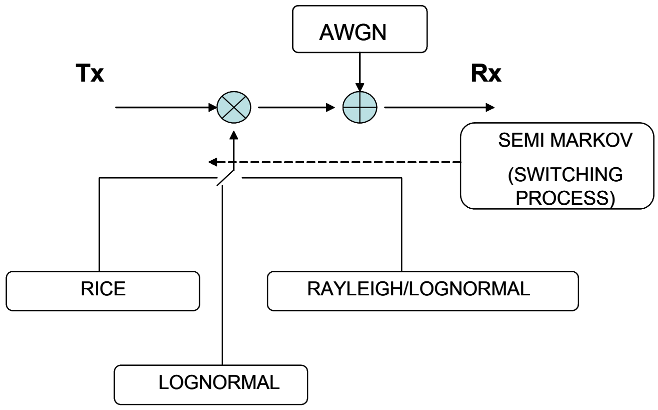


Figure No 5. Three states channel model.

For a channel model with 3 states (Figure No.5), the information given in the Table No.1 (P.681) is used for the characterization of the durations of each channel state, as well as the matrix **P** which define the process.

A Rice distribution was proposed for the characterization of a LOS condition, while that in presence of a difusse multipath with a moderate shadowing effect is used a Rayleigh-Lognormal distribution; at last, a Lognormal distribution in the case of total obstruction was used. The parameters considered for the receiver in the Urban area were: a Rice factor k=10.6 dB and a elevation angle of 21º.

The transitions matrix of the semi-Markovian process is given by

$$P = \begin{pmatrix} 0 & 1 & 0 \\ 0.65 & 0 & 0.35 \\ 0 & 1 & 0 \end{pmatrix} \qquad (17)$$

and we can see, that the model only have transitions bettween adjacent states (Figure No. 6)

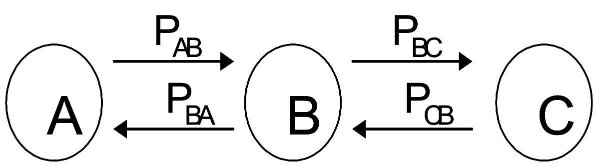


Figure No.6 Semi-Markov process with transitions between adjacent states.

In Fig No.7 is represented the time series for a three state channel model; we can see that the depth of the fading in the C state indicate the level of shadowing present, and as in the two states model, the matrix **P** could be computed by means of the transitions between states .

V.- RESULTS.

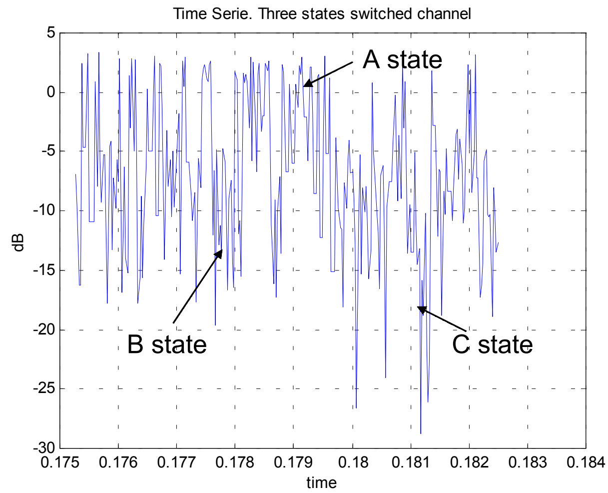


Figure No.7 Time series forThree state model.

The performance of this model with uncoded QPSK signals presents an irreductible BER (floor) around to $2x10^{-3}$. Was aplied a concatenated scheme (following Recommendation ITU-R F.1500), with a 255-233 RS code concatenaded with a ½ convolutional code. The positive effect on the performance is shows in Figure No.8.

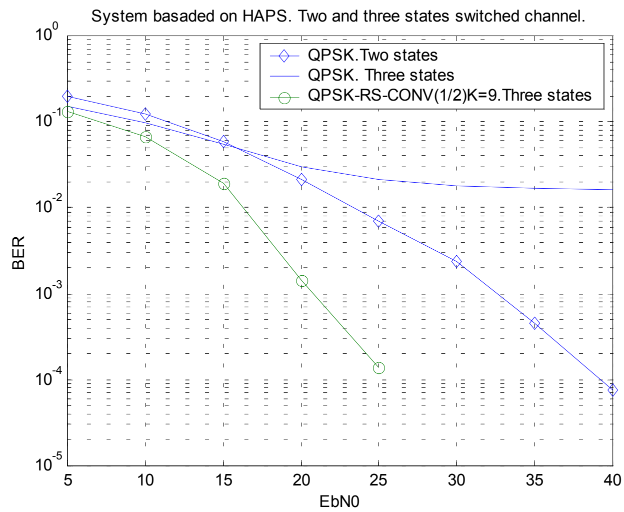


Figure No.8 Performance of the systems.

VI.- CONCLUSIONS.

The chanel model with three states, allows a better representation than the model with only two states. Its clear, that in the case of three states, the conditions could be severe, and the use a code modulation is recomendated.

This model could be used to modelate systems with more than three states and to simulate some diferents operational conditions.

The use of the semi-Markov processes permit to consider the distribution of the fading of each channel state for the model to analyze. In the case of the model based on Markov chains is used the same distribution.

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