SPACE-TIME CODING AND PROCESSING TO IMPROVE RADIO COMMUNICATION COVERAGE FROM HIGH ALTITUDE PLATFORMS (HAPs) - AN APPROACH

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ABSTRACT

In this work, Space-Time Block Coding (STBC) applied to improve performance of High Altitude Platforms (HAPs) for radio links is analysed. The communications scenario considers an aeronautical channel similar to the land mobile satellite channel model proposed in [6] which offers for medium and low angles of elevation from the ground station (worse coverage case) favourable multipath conditions to exploit space-time coding. BER performance evaluations are achieved by Monte Carlo simulations, assuming two transmit and receive antennae with uncorrelated multipath signals and QPSK modulation. The results show that significant transmit and receive diversity gains can be achieved, specially for urban zones with low LOS signal.

1. INTRODUCTION

The increase of mobile personal communications, high speed data transmission, video conference and access to Internet, make look for new technological alternatives in the wireless systems. The High Altitude Platforms (HAPs) [1,2] may be a good solution to resolve the problem of increasing needs of Telecommunications by new infrastructures in the sky. The idea of employing stratospheric platforms as flexible, without pollution and cost effective alternatives to satellite or terrestrial systems is not new. HAPs are widely recognized to be infrastructures able to yield integration and convergence of multiple interest services. In this moment, several projects are developed abroad. HELINET project, for example, is one related to traffic monitoring, remote sensing and broadband communications achieved by an European Union team from Italy, UK, Spain, Switzerland, Slovenia and Hungary [3].

HAPs can be considered as a being a hybrid architecture, they have some zones in common with terrestrial communications, particularly Fixed Wireless Access, but are similar to satellites in terms of power constraints and general network architecture. In a mobile communication context is the fact it could replace or support the terrestrial network, avoiding problems with environmental impact and electromagnetic pollution. Platform design has several constraints related to the applications to achieve: power available for the payload, stability, maximum transmit power of transmitters, link availability and so on.

In this paper, we will consider a problem related to the radio link availability from the HAPs. The scenario represented by Figure 1 considers a simplified scheme of radio coverage, but the ITU suggests that up to 240 Km diameter footprints can be served from a HAP potentially [5]. We will present an approach related to consider the compensation the effects of signal fading due to multipath propagation. The following forms of diversity are traditionally exploited to varying degrees in wireless communication systems: spectral diversity, temporal diversity, spatial diversity and polarization diversity. Recently, temporal and spatial diversities techniques have merged into a promising approach to improve signal processing performance. It is the Space-Time (S-T) coding and processing which operates simultaneously on multiple antennae. We will present an approach related to consider the incidence of S-T coding and processing to improve the radio link availability performance for an HAP operating at about 21 km high.

2. WIRELESS PROPAGATION ENVIRONMENT MODELING

The propagation of radio signals from/to HAPs to/from ground antennae is affected by the aeronautical channel in several ways, but the most important is related to the multipath phenomena and therefore with the availability of the radio link. The scenario to consider for this aeronautical channel may be represented on the Figure 1 where we can define three areas: an urban zone, a suburban or opened zone and a rural zone. The coverage by radio signals is different in each area and the performance must be evaluated for each one following particular conditions related to the angle of elevation from the ground (user terminal) antenna to HAP antenna. The urban zone may be a circular area with a radius about 25 km and with a minimum angle of elevation near to 40 degrees. Into the open zone we may consider a circular sector with an angle of elevation range from 40 to 24 degrees. The last zone may be considered between 24 and 10 degrees range for the angles of elevation. The space-time channel model for the situation above consider radioelectric stations with several antenna elements in general. The signal from the HAP (mobile) travels through a number of paths, each with its own power fading and delay. The fading can be either Rayleigh/Log-normal or Rician. These paths arrive at the receive antenna array with varying angles of arrival. The composite multipath induces a different multipath channel at each antenna because of differences in relative phasing of the paths [6,7].

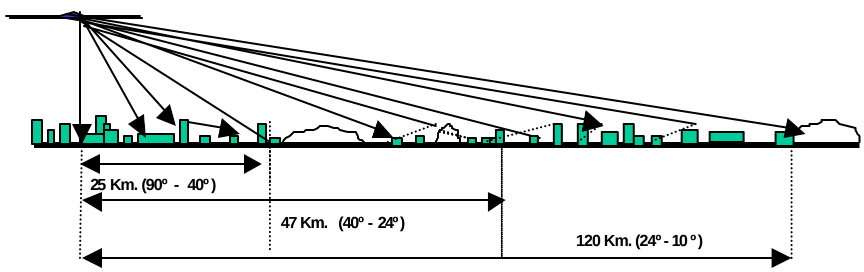

Fig.1. The HAPs communications scenario for the aeronautical channel.

3. SPACE-TIME CODING AND PROCESSING MODELS. AN APPROACH

We will present a simple scheme for transmission using two transmit antennae: STBC (S-T Block Coding). This coding strategy retain the property of having a very simple ML decoding algorithm. This scheme has been proposed as a transmission diversity option for the 3th generation systems. It consists on the use of two transmit antennae on the Base Station (BS).
The model analysed assumes flat fading and the aeronautical channel characteristics are assumed known to the receiver. The complex channel gains in general corresponds to the total contribution of the waves arriving from the "nth" transmit antenna to the "mth" receive antenna. The model under theses circumstances is an independent Rayleigh random process multiplied by an independent lognormal process when shadowing is considered. When there is direct signal added to reflected signals, Rician process must be considered alternately to Rayleigh processes, according to the percentage of time for shadowing.
The STBC strategy retain the property of having a very simple decoding algorithm, based only on linear processing at the receiver because orthogonal design allows signal decoupling [8,9]. This scheme does not require any bandwidth expansion or feedback from the receiver to the transmitter and its computation complexity is similar to that of Maximal Ratio Combining (MRC).
STBC are constructed by a P x N transmission matrix, whose entries are linear combinations of the signal constellation employed at baseband. N streams of P symbols are transmitted simultaneously from each antenna element. The received signal at each of M receiver antennas is a linear superposition of the N transmitted signals, perturbed by noise.
The basic scheme of STBC consists of two transmit antennas at the BS [9], HAPs in the context of this work.
Consider N = 2, and M antenna elements at the MS, the code matrix for this case is

$$\mathbf{G}_2 = \left[\mathbf{C}_1 \quad \mathbf{C}_2\right], \text{ with } \mathbf{C}_1 = \begin{bmatrix} x_1 \\ -x_2^* \end{bmatrix} \text{ and } \mathbf{C}_2 = \begin{bmatrix} x_2 \\ x_1^* \end{bmatrix} \tag{1}$$

Thus, the symbol sequence to be transmitted by an antenna is $x_1, -x_2^*$, and by the other x_2, x_1^*. Orthogonality is obtained since $\mathbf{C}_1^{\mathbf{H}} \cdot \mathbf{C}_2 = 0$.
Assuming flat fading, i.e. no time dispersion, the complex baseband signals received by the *m*th antenna element at the terminal, at time t_1 and t_2 (P=2), are

$$r_m(t_1) = h_{m,1} \cdot x_1 + h_{m,2} \cdot x_2 + n_m(t_1) \quad \text{and} \quad r_m(t_2) = -h_{m,1} \cdot x_2^* + h_{m,2} \cdot x_1^* + n_m(t_2) \tag{2}$$

where $h_{m,n}$ represents the complex channel gain from the nth transmit antenna to the mth receive antenna, assumed constant during the transmission of a symbol block. The term $n_m(t)$ represents the Gaussian complex baseband noise received by the mth antenna element, with power σ^2 per real component. The channel characteristics are assumed known to the receiver.
For this work, the complex channel gains ($h_{m,n}$) in general corresponds to the total contribution of the waves arriving from the nth transmit antenna to the mth receive antenna, which result independent Rayleigh process, multiplied by an independent lognormal for shadowing (assumed common for all $h_{m,n}$), and plus a common constant for Rician case.
The decoding algorithm selects the symbols that minimize the metric

$$\Psi = \sum_{m=1}^{M} \left(\left| r_m(t_1) - h_{m,1} \cdot x_1 - h_{m,2} \cdot x_2 \right|^2 + \left| r_m(t_2) + h_{m,1} \cdot x_2^* - h_{m,2} \cdot x_1^* \right|^2 \right) \tag{3}$$

which, due to orthogonality, can be decomposed as

$$\Psi_1 = \left| \left[\sum_{m=1}^{M} \left(r_m(t_1) \cdot h_{m,1}^* + r_m^*(t_2) \cdot h_{m,2} \right) \right] - x_1 \right|^2 + \left(-1 + \sum_{m=1}^{M} \sum_{n=1}^{2} \left| h_{m,n} \right|^2 \right) \cdot \left| x_1 \right|^2 \tag{4}$$

and

$$\Psi_2 = \left| \left[\sum_{m=1}^{M} \left(r_m(t_1) \cdot h_{m,2}^* - r_m^*(t_2) \cdot h_{m,1} \right) \right] - x_2 \right|^2 + \left(-1 + \sum_{m=1}^{M} \sum_{n=1}^{2} \left| h_{m,n} \right|^2 \right) \cdot \left| x_2 \right|^2 \tag{5}$$

each one for decoding symbols x_1 and x_2.

To consider Rician and Rayleigh/Lognormal fading, the channel matrix can be modeled as [10]

$$H = \begin{bmatrix} h_{1,1} & h_{1,2} \\ h_{2,1} & h_{2,2} \\ \vdots & \vdots \\ h_{M,1} & h_{M,2} \end{bmatrix} = H_{sp} + H_{sc} \tag{6}$$

where H_{sp} is the specular component (LOS case) and H_{sc} is the scattering component. The specular component can be expressed as

$$H_{sp} = a(q_t) \cdot a(q_r)^T \tag{7}$$

where $a(q_t)$ and $a(q_r)$ are the specular array responses at the transmitter and receiver. The array response corresponding to a K-element linear array, is given by

$$a(q) = \begin{bmatrix} 1 & e^{j2pd\cos(q)} & \cdots & e^{j2pd(K-1)\cos(q)} \end{bmatrix}^T \tag{8}$$

where q is the angle of arrival or departure of the specular component and d is the antenna spacing in wavelengths. The elements of the scattering component are assumed to be statistically independent unit variance complex Gaussian random variables.
The channel model for the considered scenario is an extension of the Lutz's model, to a Multiple-Input Multiple-Output (MIMO) case.

The MIMO Rice fading and Rayleigh/Lognormal fading are combined according to a shadowing percentage. When Rayleigh/Lognormal fading is present, the lognormal variation is assumed to be common to all elements of the receive array.

The parameters that characterise the channel model are: the time shadowing percentage (A), the Rice factor (c), the mean power level shadowing (μ) related to the unfaded signal and the shadowing lognormal deviation (σ).

The scheme for the MIMO channel model is shown in the figure 2.

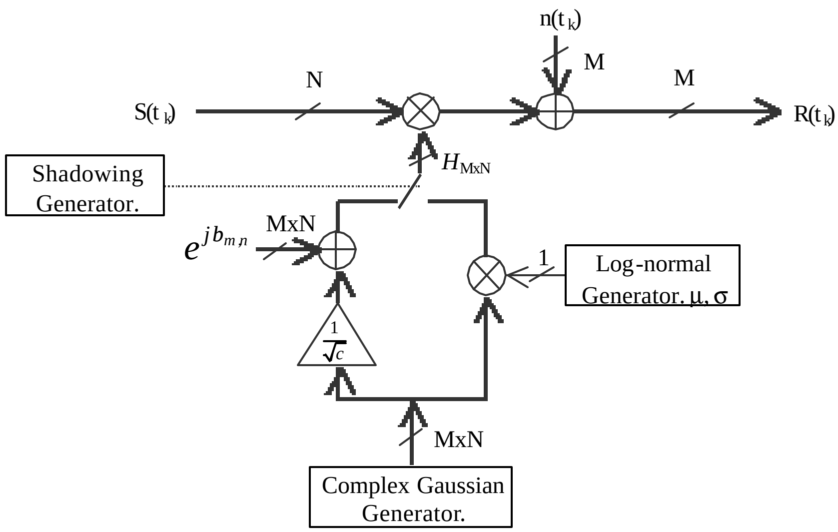

Fig. 2 MIMO channel model for simulation.

In figure 2, $R(t_k) = \left[r_1(t_k) \quad r_2(t_k) \quad \cdots \quad r_M(t_k) \right]^T = H \cdot S(t_k)$ and $S(t_k) = \left[s_1(t_k) \quad s_2(t_k) \quad \cdots \quad s_N(t_k) \right]^T$ where $S(t_1) = \left[x_1 \quad x_2 \right]^T$ and $S(t_2) = \left[-x_2^* \quad x_1^* \right]^T$ for the two transmit antennae case.

4. PERFORMANCE RESULTS

The model STBC was analysed for the band of 2Ghz, following the considerations of the ITU-R (39/8 HAPs IMT 2000) [5]. Performance results were obtained for elevation angles at the edges of each defined zones in the Figure 1. Two scenes were assumed for each one area (urban areas: city and open areas: highway). It was considered a realistic diversity situation of 2x2 scheme (MxN), which can be provided by polarization or spatial diversity. The digital signal scheme considered was the QPSK. Figures 3, 4 and 5 show the Bit Error Rate versus the link Energy per symbol (that is, referred to the mean LOS energy received per antenna), computed for 13º, 24º and 43º (degrees elevation) for uncoded and STBC signals, respectively. The simulation parameters are resumed in Table 1.

Table 1. Channel parameters for simulation.

Elevation	Area	A [%]	10log(c) [dB]	μ [dB]	σ [dB]
13º	Open	24	10.2	-8.9	5.1
	Urban	89	3.9	-11.5	2.0
24º	Open	19	17.4	-8.1	4.2
	Urban	79	11.9	-12.9	5.0
43º	Open	0.2	14.8	-12.2	3.8
	Urban	54	5.5	-13.6	2.9

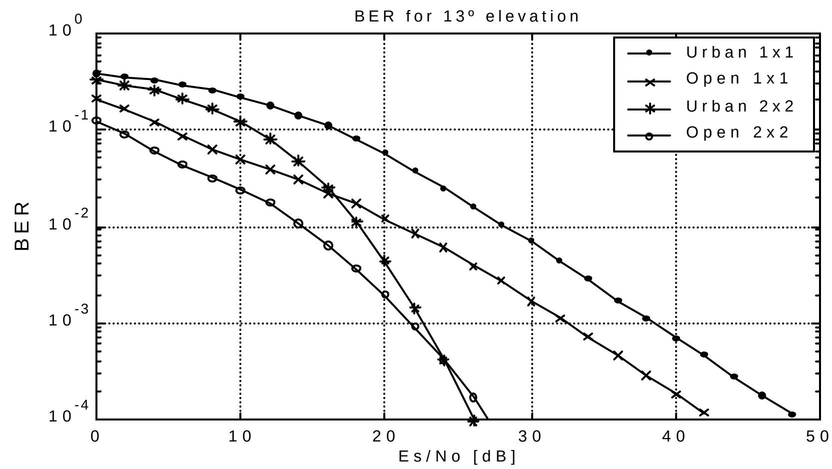

Fig. 3 BER versus Es/No for 13º elevation, Open and Urban zones, uncoded and STBC.

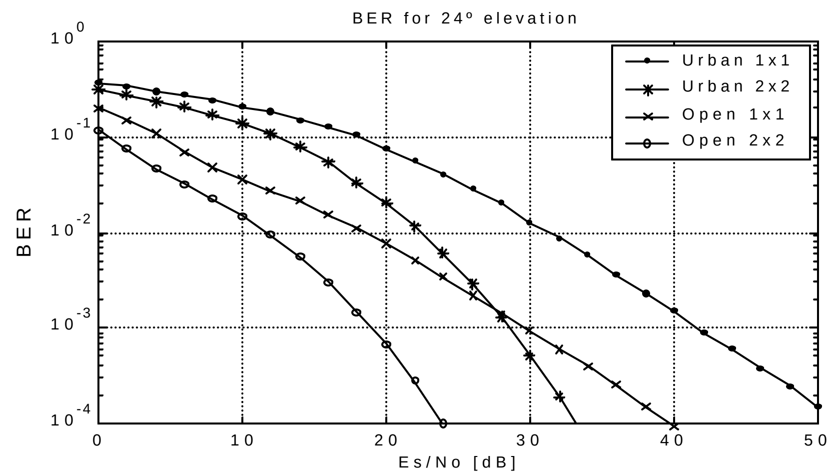

Fig. 4 BER versus Es/No for 24º elevation, Open and Urban zones, uncoded and STBC.

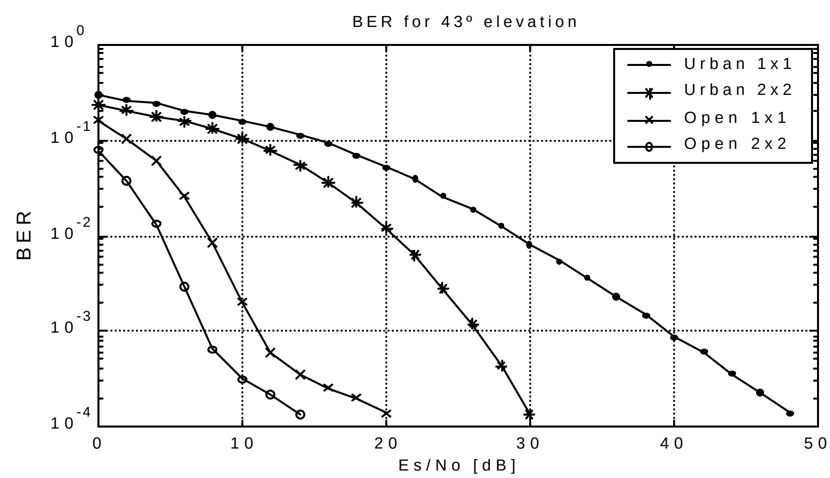

Fig. 5 BER versus Es/No for 43º elevation, Open and Urban zones, uncoded and STBC.

5. CONCLUSIONS

It was presented an approach related to the use of Space-Time Block Codes as technique for protecting digital radio links for narrowband services between HAPs and ground stations. The aeronautical channel was modelled considering three areas to analyse. The last zone is the most critical from the point of view of the bit error rate performance but it is possible to get gains more reliable using STBC concatenated with R-S codes or Turbocodes versus uncoded signals. From the point of view on coding gains, the urban areas show better results that open areas. The gains for the others situations are guaranteed.

6. REFERENCES

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