Adaptive Radio Link Design for Unmanned Aerial Vehicles with M-ary PSK Modulation and Different Coding Schemes

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***Abstract*—**Radio channel is one of the most important parts of a communication system. Main elements of a radio links are modulation, coding, number of the transmitter and the receiver antennas that can be only one, SISO (Single Input Single Output) or more than one, MIMO (Multiple Input Multiple Output). In the wireless links one of the problems is Doppler shift and another is fading. The goal in this paper is designing a radio link for Unmanned Aerial Vehicle (UAV) to the ground station. Starting from the description of the model geometry, this paper presents the results of the simulation of the SISO/MIMO channel model and calculates the rays path loss for a site considering the effects of obstacles, scattering and reflecting components. In this paper the number and location of the obstacles are deterministic but the number and the location of scatterer clusters are random. We will try to consider all the propagation elements for evaluating the actual path loss. Later we consider effect of different coding techniques and different schemes of PSK modulation for designing a radio link with minimum outage probability.

***Keywords*—**Coding, Modulation, PSK, OSTBC, QOSTBC, Alamouti codes, Outage Probability, SISO, MIMO

I.INTRODUCTION

Nowadays applications of the UAVs are a lot such as air surveillance, remote sensing etc., and military operations. Remote sensing applications require a reliable high capacity radio communication downlink channel to transmit the data from the UAV to the ground station [1]-[2]. The alternative way is to store the data on-board but his solution increases the weight of the plane, it is not very reliable, may limit the time of observation and it doesn't allow for real time data processing. Another challenge to be faced with this application is radio channel has fast fading variations due to the small particles (small in comparison to the wavelength) between transmitter and receiver, that cause strong multipath interference [3]-[4]-[15].Moreover when the UAV is manoeuvring the antenna direction changes and it can even be occluded by the UAV structure. In this case large signal losses may occur. Application of multi-antenna wireless communications systems have gained a strong interest in both academic and industrial sectors and known as Multiple-Input Multiple-Output (MIMO) transmitter and receiver. This solution increases the transmission rate and the strength of the receiving signal, if compared to traditional single-input single-output systems, which use one transmit antenna and one receive antenna. Consequently, MIMO approach is very useful technique for implementing UAVs communication system [6].

MIMO has no need for extra bandwidth and transmission power which are its important benefits [7]-[8]. The downlink of the UAV channel is used to send back to the ground station the images, sensor data, or any other information gathered during normal operations. The model is proposed in this paper consists of deterministic and random elements. Deterministic elements are related to permanent objects, like buildings, trees while random elements are related to objects with locations that aren't completely determinated in advance. With this method we will be able to have a better understanding of the channel characteristics when scenarios are changing dynamically.Variations in the property of the propagation medium, such as the occurrence of rain or snow, also can cause fading. However, this type of fading is long-term fading, which we will not consider here. Multipath also causes inter symbol interference for digital signals. For vehicular radio channels, there is also the Doppler frequency shift. Doppler shift causes carrier frequency drift and signal bandwidth spread. All these matters cause degradation in performance of modulation schemes in comparison with that in AWGN channels. In this paper we study performances of modulation schemes in fading channels. After that we first study flat-fading-channel performances of M-PSK, modulation scheme. Now an introduction to fading is described. Slow fading: In a slow fading channel, the channel impulse response changes at a much slower rate than the symbol rate. The channel coherence time is much greater than the symbol duration, or equivalently, the Doppler spreading is much smaller than the signal bandwidth.

Fast fading: If the channel impulse response changes rapidly within a signal symbol duration, the channel is classified as a fast fading channel, otherwise it is classified as a slow fading channel. The fast change of the channel impulse response is caused by the motion, or equivalently, the Doppler spreading. Quantitatively when the channel coherence time is smaller than the symbol duration, or equivalent, the Doppler spreading is greater than the signal bandwidth, a signal undergoes fast fading.

Flat fading: Flat fading is also called Frequency nonselective fading. If a wireless channel has a constant gain and linear phase response over a bandwidth which is greater than the signal bandwidth, then the signal will undergo flat or frequency nonselective fading [1]-[2].This type of fading is historically the most common fading model used in the literature. In flat fading, the multipath structure is such that the spectral characteristics of the transmitted signal is preserved at the receiver. However, the strength of the signal changes with time, due to the variation of the gain of the channel caused by multipath.

Frequency selective fading: If the channel has a constant gain and a linear phase response over a bandwidth which is smaller than the signal bandwidth, then the signal undergoes frequency selective fading. This is caused by such a multipath structure that the received signal contains multiple versions of the transmitted signal with different attenuations and time delays. Thus the received signal is unclear. Viewed in the frequency domain, some frequency components have greater gains than others. Frequency selective fading channels are much more difficult to model than flat fading channels. Each multipath signal must be modeled and the channel is considered as a linear filter. Models are usually developed based on wideband measurement.

II. CHANNEL MODEL

In our model scatterer clusters can be randomly located in the environment around the ground station. Each scatterer corresponds to a single ray and is characterized by a complex coefficient which is independent to the Direction of Arrival and the Direction of Departure (DoA and DoD), but changes in time. The complex coefficient defines the phase shift and power attenuation produced by the scatterer. In this case the receiver, receives a number of rays equal to the number of scatterers also the Line of Sight (LoS) ray, that connects directly the transmitter to the receiver [19]-[20]-[21]. For the transmitted signal s(t) we have:

$$s(t) = \operatorname{Re}\left[s_l(t) e^{j2\pi f_c t} \right] \qquad (1)$$

Where $s_l(t)$ is baseband signal. The received signal can be expressed as:

$$x(t) = \sum_n \alpha_n(t)\, s[t - \tau_n(t)] \qquad (2)$$

Where $\alpha_n(t)$ is the attenuation factor for the signal received on the n-th path with propagation delay, $\tau_n(t)$. With substituting (1) into (2), we obtain:

$$x(t) = \operatorname{Re}\left(\left\{ \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} s[t - \tau_n(t)] \right\} e^{j2\pi f_c t} \right) \qquad (3)$$

Where $r_l(t)$,the baseband complex-valued signal is:

$$r_l(t) = \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} s[t - \tau_n(t)] \qquad (4)$$

Consequently the equivalent baseband complex impulse response of the time varying multipath channel:

$$c(\tau;t) = \sum_n \alpha_n(t) e^{-j2\pi f_c \tau_n(t)} \delta[\tau - \tau_n(t)] \qquad (5)$$

The received signal may be described as:

$$x(t) = \int_{-\infty}^{\infty} \alpha(\tau;t) s(t - \tau) d\tau \qquad (6)$$

Where $\alpha(\tau;t)$ is the attenuation of the signal components with delay τ and at time t. By replacing $s(t)$ in (6) with respect to (1), we obtain the received signal equation:

$$x(t) = \operatorname{Re}\left\{ \left[\int_{-\infty}^{\infty} \alpha(\tau;t) e^{-j2\pi f_c \tau} s_l(t - \tau) d\tau \right] e^{j2\pi f_c t} \right\} \qquad (7)$$

Therefore the baseband impulse response of the channel is:

$$c(\tau;t) = \alpha(\tau;t) e^{-j2\pi f_c \tau} \qquad (8)$$

Where $c(\tau;t)$ represents the response of the channel at time t due to an impulse applied at time $t - \tau$. Therefore we have impulse response of the channel for different signals.

In our model the parameters are defined as deterministic or random. Deterministic parameters include the location of the ground station antenna, the location and the dimensions of the fixed objects e.g. buildings. Other parameters, like the location and the number of clusters (some scatterers are defined as a cluster), are selected randomly. Starting from the estimation of the number and the location of the scatterers, we can randomly generate the scatterers number and location somehow be close to the reality.

As an example, assume there is a parking for cars in a rectangular shape in a place near Rx with area is enclosed by the coordinates: x_1 to x_2 and y_1 to y_2 (these coordinates are determined in advance and the parking is a part of the site). Moreover we estimate there are between 15 and 25 cars there everyday. In this case we can generate by simulator a random number between 15 and 25 and the corresponding locations for this parking. This parking and cars in the area correspond to a cluster and scatterers respectively. Also for other objects such as trees, motorcycle parking and so on the method for scatterers generation is similar. After this step, the location and the number of all scatterers are defined and they can be treated as deterministic numbers. Since the location of the base station and the UAV is also given, now it is possible to calculate Doppler shift and delay time according to the location of each scatterer, considering that each scatterer corresponds to one reflected ray. If an obstacle (like a building) is located between one or some scatterers and the Rx, the simulator eliminates the rays reflected by these scatterers. The effect of the fixed obstacles can be different. It can be a reflector (depending on the relative position of the UAV and the ground antenna), or, if it is a shadowing building between the scatterers and the receiver, simulator eliminates the rays. Otherwise the obstacles have no effects in the calculations.

A. Effect of Error in SISO Systems

In a SISO system, the basic equation describing the transmission signal to a SISO system is $y = h * s + n$ where $h = |h| e^{j\varphi h}$ and $h_e = |h_e| e^{j\varphi h}$. We can define a new vector:

$$\tilde{r} = h_e^* r = h_e^* h s + h_e n = |h_e||h| s + h_e n \tag{9}$$

If we set in (x) where $x = h$ follows:

$$\varepsilon = \frac{|h_e| - |h|}{|h|} \tag{10}$$

and:

$$\tilde{r} = |h|^2 (1+\varepsilon)s + |h|(1+e)e^{j\varphi h} n \tag{11}$$

Thus the detector will select the signal that minimizes the equation [2]-[6]-[8]:

$$\begin{aligned} \tilde{s} &= \arg\min |\tilde{r} - |h_e||h| s|^2 = \\ &= \arg\min ||h|^2 (1+\varepsilon)s + |h|(1+e)e^{j\varphi h} n \\ &- ||h|(1+\varepsilon)||h| s|^2 \end{aligned} \tag{12}$$

B. Effect of error in SIMO systems

In transmitting a signal via a SIMO system, the equations describing the transmission process are:

$$\begin{aligned} r_1 &= h_1 * s_1 + n_1 \\ r_2 &= h_2 * s_2 + n_2 \end{aligned} \tag{13}$$

By combining these two relations follows:

$$\begin{aligned} \tilde{r} &= (1+e)[|h_1|^2 + |h_2|^2] + h_{1e}^* n_1 + h_{2e}^* n_2 \\ n &= h_{1e}^* n_1 + h_{2e}^* n_2 \\ \tilde{r} &= (1+e)[|h_1|^2 + |h_2|^2] + n \end{aligned} \tag{14}$$

and by successive substitutions:

$$\tilde{r} = (1+e)[|h_1|^2 + |h_2|^2] + h_{1e}^* n_1 + h_{2e}^* n_2 \tag{15}$$

where $n = h_{1e}^* n_1 + h_{2e}^* n_2$, n (x) is transformed as follows:

$$\tilde{r} = (1+e)[|h_1|^2 + |h_2|^2] + n \tag{16}$$

So again, the detector will select the signal that minimizes the equation:

$$\hat{s} = \arg\min |(1+e)(|h_1|^2 + |h_2|^2)s| \tag{17}$$

C. Effect of error in MIMO systems

For the MIMO system, equations are:

$$\begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \tag{18}$$

and:

$$\begin{pmatrix} r_1 \\ r_2^* \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} + \begin{pmatrix} n_1 \\ n_2^* \end{pmatrix} \tag{19}$$

Introducing again an error in the transmitted signal. Transmission equations are shown as follows [8]-[14]:

$$\begin{pmatrix} \tilde{r}_1 \\ \tilde{r}_2 \end{pmatrix} = \begin{pmatrix} h_{1e} & h_{2e} \\ h_{2e}^* & -h_{1e}^* \end{pmatrix} \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} s_1 \\ s_2 \end{pmatrix} + H_{v_e}{}^{H} \tilde{n} \tag{20}$$

where:

$$H_{ve}{}^{H} = \begin{pmatrix} h_{1e}^* & h_{2e} \\ h_{2e}^* & -h_{1e} \end{pmatrix} \tag{21}$$

The diagrams the performance of each transmission system by introducing various faults are those that follow:

D. Orthogonal Space-Time Block Codes (OSTBC)

A rectangular space-time code is a linear code that has the following property [6]:

$$S * S^H = \sum_{n=1}^{N} |s_n|^2 * I \tag{22}$$

Where the identity matrix and the index denote the Hermitian complex inverse. The basic property of OSTBCs is that any two columns of the matrix between the transceiver is rectangular. This means that the sequences of signals transmitted from any two antennas are orthogonal. The orthogonality property of the columns is one that gives the great advantage of orthogonal space-time codes, which is the ability of simple linear decoding at the receiver with the Maximum Likelihood (ML) criterion. Thus, each symbol is decoded separately at the receiver using only linear processes. To achieve linear decoding, the receiver is necessary to have full knowledge of the channel, which remains constant for the duration of a block. Another advantage is that the OSTBCs achieve maximum diversity gain, which for transmitting antennas and receiving antennas in Rayleigh fading environments has proven to be equal to $N * M$. Hence, OSTBCs cannot get maximum diversity gain and maximum transmission rate together with the sole exception of the code of Alamouti (Alamouti code).With entries $\pm s_{ij}$. Real OSTBCs that provide maximum diversity gain, maximum code rate and ML decoding are simple for n = 2, 4 and 8 antennas. Generalized real OSTBCs: The transmission matrix is a table x with real inputs 0, $\pm s_{ij}$. Generalized real OSTBCs that provide maximum diversity gain, maximum code rate and ML decoding are simple for any number of transmitting antennas. The Alamouti code for two antennas and presented in detail in the next section. Generalized Complex OSTBCs: It orthogonal codes whose transmission matrix is an orthogonal matrix with complex-valued inputs $\pm s_{ij}, \pm s_{ij}^{*}, \pm s_{ij} j, \pm s_{ij}^{*} j$. Generalized Complex OSTBCs that provide maximum diversity gain, maximum code rate and simple ML decoding does not exist [8].

Most common coding technique for error correction in flat fading channels is Alamouti Coding [5].This paper purpose is showing that in some situations (depend to SNR) Orthogonal and Quasi Orthogonal Space Time Block Codes (OSTBC and QOSTBC) have better performance [6]-[11].In telecommunications technical differentiation relates to a method for improving the reliable transmission of a signal using two or more communication channels with different characteristics. The segregation plays an important role in combating interference thus avoiding errors. The strong fluctuation of signal strength in adverse environments can reach 20-30 dB and has even lead to the interruption of communication when is compared to received signal levels fall too low. The diversity technique is based on the fact that individual channels are characterized by different levels of interference. Multiple copy of the same signal can be transmitted from the transmitter and then be taken and attached to the receiver. Alternatively error detection code (forward error corrector) can be added so that different parts of the message to be transferred to different channels. It is important to ensure that different copies of the original signal are independent, i.e. are affected differently by the channel. The advantage of this concept is easily understood if you consider the simple case of having two versions of the signal arriving at the receiver. This idea, although very simple in understanding has been highly effective. For this reason, many different approaches have been developed differentiation. Indicatively [4]-[7]-[18]:

- spatial diversity
- frequency diversity
- time diversity
- polarization diversity
- multiuser diversity

The spatial diversity, also called Antenna Diversity is a simple, efficient and widely used technique applied to reduce the negative effects of multipath fading environments from many scatterers. The diversification of space is to use multiple antennas transmitting and / or receiving stations, which are located some distance from each other that the different versions of the signal arriving at each of the receive antennas to be subject to different fading. The distance between the antennas must be such as to ensure that the different versions of the signal are uncorrelated, i.e. affected by uncorrelated manner of their arrival from the channel. Typically, this distance should be sometimes greater than the signal wavelength [6].Originally developed diversity reception techniques using multiple antennas at the receiver at distances sufficient to obtain uncorrelated signals. Systems operating with a transmitting antenna and multiple receive antennas as mentioned previously called SIMO (Single Input-Multiple Output) systems. The main disadvantage of diversity reception is that it makes the receivers more complex and more expensive. For this reason, making the diversity mainly applied to the base stations to improve the performance of the systems. The receiving stations serving hundreds or thousands of terminals, and so it is economical to add equipment to base stations to achieve diversity. Another reason why making diversity was not extended to the terminals is the lack of space [8].With these data, the technical diversity transmission emerges as an interesting alternative. The technical diversity emission developed more recently and consists in having multiple antennas transmitting at distances sufficient to transmit signals to undergo uncorrelated fading on the channel. The diversification of transmission has the advantage that by simply adding some transmitting antennas at the base station ensures diversity gain for all users. Furthermore, it has been shown that the same antenna can be used for differentiation of transmission at the downlink, i.e. the communication base station to the terminals, and for diversity reception in the uplink, namely the communication terminal to the base station. With the differentiation time the same data is transmitted multiple times resulting errors resulting diffuse in time [9]-[10]. Finally, techniques have been developed space diversity transmitter-receiver, using multiple transmitting antennas and multiple receiving antennas simultaneously. These MIMO systems have the advantage of providing even greater diversity gain using the appropriate mechanism making. Various techniques have been proposed for these transmission systems, the technical space-time coding and spatial multiplexing techniques are essential [5]-[11]. A typical example of the latter case is the diversification of polarization (polarization diversity). It is known that some of the characteristics transmitted in wireless communications are different for waves with horizontal and vertical polarization waves. Multiple reflections between the transmitter and the receiver lead to a change in polarization of radio waves, while conveying some of the energy of the transmitted signal in orthogonal polarized wave.

Because of this characteristic of multichannel radio vertical / horizontal polarized transmitted signals are also horizontal / vertical components. A very important parameter that describes the polarization diversity system is the correlation coefficient between the obtained spectra of the signals. Since the diversity bias requires use of a dual-polarized antenna only the final state necessarily leads to certain correlation signals. But studies show that the systems of multiple antennas can achieve a significant diversity gain [9]-[12]-[13].There are various diversity reception techniques used in these systems and will be presented below.

E. Method of maximal ratio (Maximum Ratio Combining - MRC)

We consider a system which takes M copies of the transmitted signal through M different routes. Assuming that r_m is the m-th received signal which is determined as follows: $r_m = a_m * s + n_m$ where n_m is the sample of AWGN. A Maximum Likelihood (ML) decoder combines the M signals are transmitted in order to find the signal that is most likely to have been transmitted. Consider a phase detection where the receiver knows the channel gain a_m .Once the noise samples are independent Gaussian random variables, the received signal is also independent Gaussian random variable for a given channel gain and transmitted signal. For this reason, the conditional probability density function of the received signal is [4]-[7]-[14]:

$$f(r_1, r_2, ..., r_m \mid s, a_1, a_2, ..., a_M) = \frac{1}{(\pi N_0)^{\frac{M}{2}}} \exp\left\{\frac{-\sum_{m=1}^{M} | r_m - s a_m |^2}{N_0}\right\} \quad (23)$$

where $N_0 / 2$ is the square of the standard deviation of the real and imaginary part of the complex variable Gaussian noise.

To maximize this show the receiver must find the most suitable transmitted signal which minimizes the average $\sum_{m=1}^{M} | r_m - s a_m |^2$ .We note that no diversity, M = 1, the function that minimizes the above condition is $| r_1 - s * a_1 |^2$ or $| r - s * a |^2$. This is equivalent to calculate the closest among all the possible transmitted signals. For a constellation with equal energy symbols we have, for example PSK, resulting:

$$\begin{aligned} \hat{s} &= \arg\min \left(\sum_{m=1}^{M} | r_m - s a_m |^2 \right) \\ &= \arg\min \left(\left| - s \sum_{m=1}^{M} a_m r_m^{*} - \sum_{m=1}^{M} a_m^{*} r_m \right| \right) \\ &= \arg\min \left(\left| \sum_{m=1}^{M} a_m^{*} r_m - s \right|^2 \right) \end{aligned} \quad (24)$$

For this reason, the ML decoding is similar to the system with no differentiation if instead of the quantity $r a^*$ use an average of the received signals $\sum_{m=1}^{M} a_m^* r_m$ .Summarizing the MRC using a filter, which is the optimal receiver for each of the received signals and using the quantity $\omega_m = a_m^*$ combines the outputs of the filters. This process is known as MRC, is effective but complicated as it requires information of all aspects of fading channels.

F. Select of better signal (Selection combining)

The receiver selects the best received signal for demodulation and sensed, in accordance with certain criteria. These criteria relate to the total received signal power, the relationship is:

$$r = \mathrm{C}\left(r_1, r_2, ..., r_m\right) \quad (25)$$

Where C represents the selection of the signal. In practice, however, these figures are difficult to control because its control implies the existence of a mechanism of assessing these parameters in each antenna. A variation of this method is the existence of a switch, which connects one of the antennas to the receiving system. Where the received signal falls below a certain threshold, the switch selects another antenna for continuing the reception.

G. Cumulative Shooting with Weight Coefficients (Gain combining)

With this method, the signal is used by the receiver is derived as a linear combination of the received signals.

$$r = \sum_{m=1}^{M} a_i \, r_i \quad (26)$$

H. Method of Equal Weight Coefficients (Equal Gain Combining)

In the method of equal weight coefficients or simple aggregate making (equal gain combining) the coefficients are chosen so that the signals from the antennas are in phase and added. Although it is less suitable, this method with in-phase detection is often an attractive solution as it does not require an estimate of the amplitude and therefore gives results less complex than the optimum MRC. However, this method limited in practice when we refer to M-PSK signals. Indeed, for signals with unequal energy symbols such as M-QAM necessarily to estimate the width of the channel and therefore in such configurations must be used MRC for best performance [11]-[13].

III. SYSTEM ARCHITECTURES

Depending on the number of antennas that are on the show but also in making a data transmission system, the system is characterized as a system of SISO, SIMO, MISO and MIMO.SISO systems are less complex than a MIMO in these systems there is a transmitting antenna and one receiving antenna. This makes it easier to predict the behavior of systems as the parameters to be taken into account is less than in MIMO in which interactions are numerous and cannot be determined without detailed studies. Therefore the next section will be described in the simplest case MIMO system with Tx = Rx = 1.

A. Space Time Block Code (STBC)

The space-time coding is widely used technique in wireless communications for transmitting different copies of information from multiple antennas and the use of different versions of the same information to the receiver in such a way as to improve the system performance. The fact that the transmitted signal propagates in fading environments and thermal noise has the effect of altering the original information and any copies of this information, they arrive at the receiver, to be more accurate than others. The abundance of such signal components arriving at the receiver enables to exploit one or more copies of the original signal for accurate decoding of the signal. The space-time coding basically combines (combining) all copies of the original signal, obtained in the most appropriate manner in order to recover from them the best possible information. The space-time coding is usually denoted by a symbol table. Each series represents a time (timeslot), in which the transmitted symbol, and each column the number of transmitting antennas which send symbols for time [1, T]. The block of symbols is the set of symbols that are transmitted from all the antennas the period T. Each modulated symbol S_{ij} denotes the symbol sent at time i from antenna j. For example, the element of the second row and third column of the matrix, S_{23} ,is the symbol transmitted from the third antenna to the second time duration of the block[12]-[16].

$$\begin{array}{cc} & \textit{transmit}\ \text{antennas} \\ \textit{time}\ \text{slots} & \begin{pmatrix} s_{11} & \cdots & s_{1n_T} \\ \vdots & \ddots & \vdots \\ s_{T1} & \cdots & s_{Tn_T} \end{pmatrix} \end{array} \quad (27)$$

The symbol transmission rate depends on the specific space-time coding. We consider that a configuration is used with data and transmitted constellation different symbols during a block. This means that during a block entering the encoder $K\,2^{M}$ bits, which are assigned into symbols. Rate of the code, i.e. the average number of symbols transmitted in the duration of a block is defined as transmission. Consider a MIMO transmission system transmitting antennas and receiving antennas. The transmitter antennas simultaneously transmitting symbols S_{ij} from the matrix below (transmission matrix), where each column corresponds to the transmitted symbols from all the transmitting antennas [7]-[9].

$$s = \begin{pmatrix} s_{11} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mn} \end{pmatrix} \; \textit{for}\ \mathrm{i} = 1, 2, \ldots \mathrm{m} \quad (28)$$

$$\textit{and}\ \mathrm{j} = 1, 2, \ldots n$$

With assumption that the symbols in the matrix are independent and are selected from a constellation in data transmission, depending on the configuration selected.

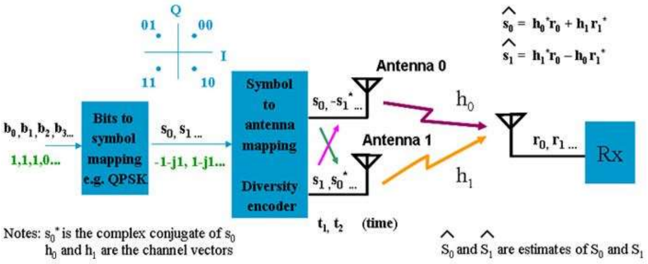


Fig.1 MIMO transmission

These symbols are passed through a multipath fading channel, which is quasi-stationary i.e. varied, but slowly enough to be regarded constant during at least T moments required for transmission of all the columns of the matrix unit.

The following table gives the factors for each signal multiplied table transmission, when crossing the channel.

$$H = \begin{pmatrix} h_{11} & \cdots & h_{1N} \\ \vdots & \ddots & \vdots \\ h_{M1} & \cdots & h_{Mn} \end{pmatrix} \quad (29)$$

The point is the intermittency factor (fading coefficient) between the transmitting antenna and the receiving antenna is given by the relationship: $h_{ij} = |h_{ij}| e^{j\varphi}$ where $|h_{ij}|$ and φ the amplitude and phase of the complex gain of the channel, respectively [17].

The data in the matrix h_{ij} should are independent. This independence is ensured by placing the antenna at sufficient distance between them.

Statistical models for fading channels mentioned above can be applied to profits h_{ij} the MIMO channel. For example, in a channel with uncorrelated Rayleigh fading each element of a channel will be an independent and identical distributed (independent and identical distributed - iid) complex Gaussian variable, while the width of $|h_{ij}|$ distribution will follow Rayleigh. The communication system is called open-loop (open-loop systems), when the receiver has full information of the channel (Channel State Information(CSI), while the transmitter has no information on his condition. The receiver that knows the coefficients h_{ij} panel of the channel at any time and may use them in decoding and demodulation and sensed. By contrast, in closed loop systems (closed-loop systems), the receiver sends back some information at the transmitter for channel through a feedback channel (feedback channel). This information is used by the transmitter to improve system performance. By doing this, of course, increases the complexity of the telecommunications system. The systems studied in this work are open loop[3]-[11]. Based on the above, the equation describing the transmission in MIMO system are:

$$Y = H * S + N \tag{30}$$

Where the matrix includes the baseband complex signal received by the receiving antennas in time:

$$Y = \begin{pmatrix} y_{11} & \cdots & y_{1N} \\ \vdots & \ddots & \vdots \\ y_{M1} & \cdots & y_{Mn} \end{pmatrix} \tag{31}$$

The maximum value that can get the transmission rate of the code is the unit (full rate). Generally the higher the transmission rate, the smaller the gain diversity, so chosen depending on the application, the appropriate code. The only code that achieves maximum diversity gain with simultaneous rate equal to the unit belongs to the class of orthogonal codes and presented extensively then.

The space-time codes are divided into two major categories:

- (Orthogonal Space Time Block Codes - OSTBCs)
- (Quasi-Orthogonal Space Time Block Codes - QOSTBCs)

Assume a telecommunications system with two transmitting and one receiving antenna. Two signals are emitted simultaneously from both antennas at a given time and encoded in space-time, as shown below:

Antenna	**0**	**1**
Time t	s_0	s_1
Time (t + T)	$-s_1^*$	s_0^*

Table 1.Transmission of symbols in Alamouti STBC

The block symbols take two moments. The first time emitted the modulated symbols s_0 and s_1 and second symbols $-s_1^*$ and s_0^*, Where the "*" denotes the conjugate of a complex number. It is considered that the channel at time t is defined fading with $h_0(t)$ for the first antenna and $h_1(t)$ for the second antenna. Assume the fading is constant during two consecutive symbols, and the duration of a symbol is obtained:

$$\begin{aligned} h_0(t) &= h_0(t+T) = h_0 = a_0 e^{j\theta_0} \\ h_1(t) &= h_1(t+T) = h_1 = a_1 e^{j\theta_1} \end{aligned} \tag{32}$$

The signals received at the time points t and (t+T) are:

$$\begin{aligned} r_0 &= r_0(t) = h_0 s_0 + h_1 s_1 + n_0 \\ r_1 &= r_1(t+T) = -h_0 s_1^* + h_1 s_0^* + n_1 \end{aligned} \tag{33}$$

With n_0 and n_1 symbolized the noise at the receiver as complex random variable.

Then create the following signals to the linear receiver (combiner) and sent to the maximum likelihood detector (maximum likelihood detector):

$$\begin{aligned} \tilde{s}_0 &= h_0^* r_0 + h_1 r_1^* \\ \tilde{s}_1 &= h_1^* r_0 - h_0 r_1^* \end{aligned} \tag{34}$$

Substituting the relations for r_0 and r_1 finally obtained:

$$\begin{aligned} \tilde{s}_0 &= (a_0^2 + a_1^2) s_0 + h_0^* n_0 + h_1 n_1 \\ \tilde{s}_1 &= (a_0^2 + a_1^2) s_1 - h_0 n_1^* + h_1^* n_0 \end{aligned} \tag{35}$$

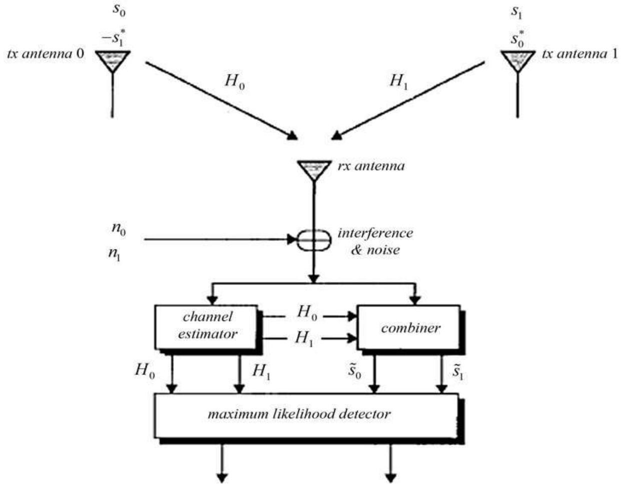


Fig. 2 the transmission system with coding Alamouti space-time codes with two transmitting antennas and one receiving antenna

B. The Alamouti Codes Scheme for 2xM

In some applications, it is desirable greater diversity gain is possible application of the Alamouti code for two transmitting antennas and M receive antennas, thus ensuring diversity gain 2xM. Below is the case of the 2x2 system, which generalizes easily to 2xM.

Define tables H and R:

$$H = \begin{pmatrix} h_0 & h_2 \\ h_1 & h_3 \end{pmatrix} \qquad R = \begin{pmatrix} r_0 & r_2 \\ r_1 & r_3 \end{pmatrix} \tag{36}$$

The element of the first row and the second column is the intermittency factor of the channel between the first transmitting antenna and the second receiving antenna. The table represents the received by the two antennas signals during the two moments which is the period of the block symbols. The lines concerning the times and the columns receiving antennas. Thus, the symbol of the second row and first column is the received symbol from the first antenna to the second time. The matrix of transmission is same as the case 2x1, i.e.:

$$S = \begin{pmatrix} s_0 & s_1 \\ -s_1^* & s_0 \end{pmatrix} \tag{37}$$

Finally, apply the received signals:

$$\begin{aligned} ro &= h_0 s_0 + h_1 s_1 + n_0 \\ r1 &= -h_o s_1^* + h_1 s_0^* + n_1 \\ r2 &= h_2 s_0 + h_3 s_1 + n_2 \\ r3 &= -h_2 s_1^* + h_3 s_0^* + n_3 \end{aligned} \tag{38}$$

Where n_o, n_1, n_2, n_3 is complex-valued random variables representing receiver noise and interference. The linear receiver generates the following signals, which are then sent to the maximum likelihood detector:

$$\begin{aligned} \hat{s}_o &= h_o^* r_o + h_1 r_1^* + h_2^* r_2 + h_3 r_3^* \\ \hat{s}_1 &= h_1^* r_0 - h_0 r_1^* + h_3^* r_2 - h_2 r_3^* \end{aligned} \tag{39}$$

Substituting r_0 and r_1 in the above relations follows:

$$\begin{aligned} \hat{s}_o &= (a_0^2 + a_1^2 + a_2^2 + a_3^2) s_0 + h_0^* n_0 + h_1 n_1^* + h_2^* n_2 + h_3 n_3^* \\ \hat{s}_1 &= (a_0^2 + a_1^2 + a_2^2 + a_3^2) s_1 - h_0 n_1^* + h_1^* n_0 - h_2 n_3^* + h_3^* n_2 \end{aligned} \tag{40}$$

These signals are easily detected by the receiver maximum likelihood, and the system performance 2xM. This is shown below where given in detail the results of simulations.

IV. RECEIVERS IN THE MIMO SYSTEMS

In most systems the complexity MIMO transmitter in terms of signal processing is low, and the bulk of the signal processing is performed at the receiver. The receptors are classified into the following two main categories:

A. Receivers Maximum Likelihood (Maximum Likelihood Detector)

The maximum likelihood receivers provide better system performance (maximum diversity gain and better error probability curve), but using the most sophisticated detection algorithm (detection). The receiver calculates the maximum likelihood received signal for each of the elements of the modulation constellation that may be transmitted, knowing the channel and without taking into account the effect of noise.

Then compare each received signal with each of the measured signals and calculate their distances. Then, deciding that the element of the constellation leading to the shortest distance is the signal that has been transmitted. The main disadvantage of maximum likelihood receiver is the computational complexity, which grows prohibitively for configurations with large constellation symbols.

B. Multiple Receive Antennas

Alamouti STBC can be used in MIMO communications. It benefits from additional diversity and array gain due to the presence of multiple receive antennas. However, it does not use MIMO multiplexing capabilities. Hence it is suboptimal as it does not achieve the highest possible throughput. The treatment with multiple receive antennas is very similar to the treatment with a single receive antenna except that we now manipulate vectors.

The Alamouti STBC has full rate and full diversity. Only for two transmit antenna can a space–time block code achieve both properties (except for real valued constellations). STBC designs for more than two transmit antennas can achieve (a) full rate but not full diversity or (b) full diversity but not full rate. Alamouti STBC transmission is equivalent to a SISO channel with SNR equal to:

$$SNR = \frac{\overline{P}}{2\sigma_n^2}(|h_1|^2 + |h_2|^2) \qquad (41)$$

Where $\overline{p}$ total energy is transmitted from all antennas and σ_n^2 is noise power.

The transmission rate is equal to four bits per transmission. From the slopes of the curves at high SNR, the diversity gain of the Alamouti STBC for a 2×1 MISO is equal to two while the diversity gain of the Alamouti STBC for a 2×2 MIMO system is equal to four and outage probability is lower for the 2×2 MIMO.

C. STBC for More than Two Transmit Antennas

The code rate of an STBC is the number of symbols transmitted on average over a block. If the rate is equal to 1, then the STBC has full rate. The data to be transmitted is encoded, using the same encoder, into multiple code-words, or blocks, of same duration. Multiple copies of the same block are transmitted in space and in time.

The STBC spreads over a number of T block transmissions and over all transmit antennas. Hence, decoding is based jointly on T blocks at the receiver. The main assumptions associated with STBC transmission are as follows. Unlike Alamouti STBC, the power is not always equally distributed across the transmit antennas (unequal power allocation might be necessary to guarantee orthogonality of the STBC).

D. Orthogonal and Quasi-orthogonal Designs

For more than two transmit antennas, two classes of STBC codes can be distinguished:

The class of orthogonal STBC and the class of quasi-orthogonal STBC.

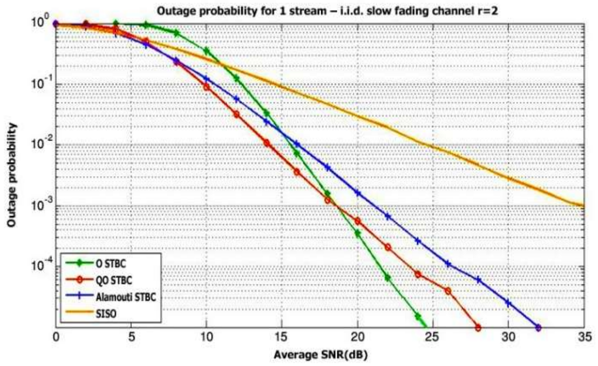
- Orthogonal STBC: The lines of the STBC matrix are orthogonal. The advantage of orthogonal STBC are: (a) they have full diversity and (b) the optimal receiver is very simple as it is a simple matched filtering. The disadvantage is that those codes do not achieve full rate, with noticeable exception of the Alamouti STBC for two transmit antennas (as well as real valued constellations).
- Quasi-orthogonal STBC: The lines of the STBC matrix are not orthogonal. The orthogonality is sacrificed for rates that are higher than the orthogonal counterpart. However, the optimal receiver is more complex (ML receiver in general).

E. Comparison between Orthogonal STBC and Quasi-orthogonal STBC

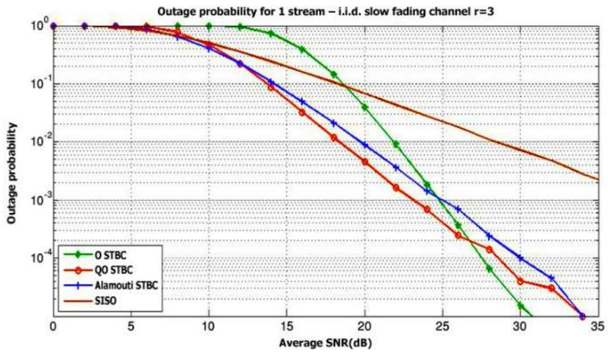
The symbol error rate (SER) at the output of the receiver as a function of the SNR for the orthogonal STBC and that of the quasi-orthogonal STBC, assuming that a QPSK constellation is transmitted over an i.i.d.(Independent and Identical Distribution) complex Gaussian (Rayleigh) fading channels. The SER for a SISO channel is shown as a reference. QOSTBC has a worse SER than OSTBC. For a fixed input constellation, the SER of QOSTBC is degraded due to the inter-stream interference (or non-orthogonality of the QOSTBC). However, the OSTBC shown has half the rate of the QOSTBC.

V. SIMULATION RESULTS

In this part, the simulation results are shown. The site (ground station) consist of some fixed objects like buildings and scatterers around the receiver antenna. The number and location of the scatterers are selected randomly somehow the site be similar to the reality. The simulation has done by MATLAB. The modulation is M-ary PSK. It is clear for some amounts of SNR, QOSTBC and OSTBC have better performance than Alamouti. Therefore with attention to the fig.3, depends on average SNR it is possible to change the coding method also factor (M) of the modulation for better Outage probability. For this purpose just needs that receiver with measurement of the SNR, sends a message to the UAV for changing modulation and coding scheme.



a



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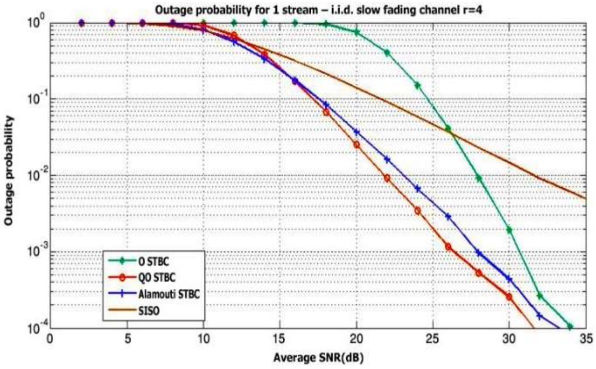
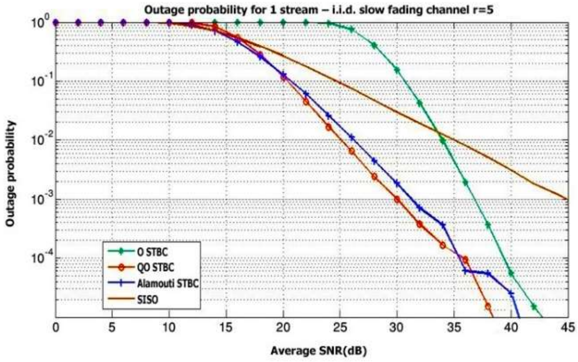


c



d

Fig. 3 Outage probability of OSTBC, QOSTBC, Alamouti and without coding (SISO) for a(r=2),b(r=3),c(r=4) and d(r=5) Rayleigh slow fading channel

VI.CONCLUSION

The most popular STBC is the Alamouti STBC. It is designed for a two-transmit antenna system. It is the only STBC code that achieves both full rate and full diversity (except for real constellation based STBC). Alamouti STBC minimizes the outage probability for an i.i.d. transmission.

For complex constellations and more than two transmit antennas, no STBC can be designed that achieve both full diversity and full rate. This coding method is suggested for error correction in many communication links with multipath fading [5].In this paper is showed that for some amounts of SNR,OSTBC and QOSTBC have lower outage probability and with combination with M-PSK as an adaptive method, a radio link for flat fading has better performance.

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