Dual Polarization Waves Reuse Scheme in Cross Polarization Channel

Jingshown Wu and Shan-An Yang
Room 519
Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan, 106
R.O.C

Abstract

In this paper, we propose a dual polarization waves Reuse Scheme, which will double the wireless communication capacity. Due to the cross polarization and antenna misalignment, most of current wireless communication systems only use single polarized wave to carrier information. Some of them may employ other polarized wave for diversity application. The proposed scheme, which simultaneously utilizes two polarized waves to carrier information, has the ability to reduce the effect of cross polarization and antenna misalignment significantly. The result shows that even in the large misalignment and cross polarization environment the BPSK system with the proposed scheme still maintains satisfactory performance.

Introduction

The demand of wireless communications including mobile cellular and satellite communications increases rapidly. many mobile cellular systems are deployed globally and several low orbit satellite communication systems are planned and deployed experimently. Because the demand of wireless communications increases so badly, effective spectrum utilization becomes an important issue. Many techniques such as microcell, picocell or employing millimeter waves are developed successfully. However polarization waves reuse is another way to effectively utilizes the spectrum. Due to the cross polarization and antenna misalignment problems, the dual polarized waves resue is precluded in most wireless communication system[1].Some of the current wireless communication systems use the polarization wave for diversity purpose to increase the availability[2,3]. In the literature, a few polarization wave reuse trials for satellite communication systems were reported. These trials employ different polarization waves for different transmitter and receiver pairs[4-9]. In other words, the two different polarized waves are used as two independent channels. The results of these trials showed that when the weather condition is good, the system capacity is doubled. However, when the weather condition is not ideal, such as heavy rain, which induces cross polarization or polarization shift, the system degrades significantly and becomes inpractical. In this paper, we propose a polarization waves reuse scheme which will effective utilize the spectrum.

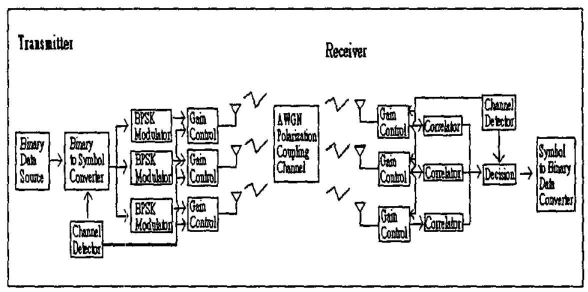

Figure 1 The system Block Diagram

System description

The system with the proposed polarization wave reuse scheme is shown in Figure 1. In the transmitter the symbol converter translates the binary data into symbols which are suitable for each branch according to the state of the channel. These signals are input to the BPSK modulators to modulate the carriers and then transmitted by three orthogonal antennas. The channel is modelled by the additive white Gaussian noise (AWGN) channel and characterized by the channel matrix $\underline{X}$, which may vary slowly comparing with the symbol rate. The receiver also contains three orthogonal antennas followed by three correlators and the decision circuit, which estimates the received symbol according to the channel state and the correlator outputs. The correlator outputs are also used as the input of the channel detector to estimate the channel matrix for adaptive adjustment.

At the transmitter, the BPSK signal can be expressed as

$$\vec{S}(t) = \alpha_1 \cos(wt)\vec{i} + \alpha_2 \cos(wt)\vec{j} + \alpha_3 \cos(wt)\vec{k} \quad (1)$$

where $\vec{i}, \vec{j}$ and $\vec{k}$ are the unit vectors of the 3-dimentional Cartesian coordinates and w is the angle carrier frequency, and α_1, α_2 and α_3 are the amplitudes.

At the receiver, the received signal at the three receiving antennas is given as follows.

$$R(t) = R_x\vec{i} + R_y\vec{j} + R_z\vec{k} \quad (2.1)$$

$$R_x = x_{11}\alpha_1 \cos(wt) + x_{12}\alpha_2 \cos(wt) + x_{13}\alpha_3 \cos(wt) + n_1(t) \quad (2.2)$$

$$R_y = x_{21}\alpha_1 \cos(wt) + x_{22}\alpha_2 \cos(wt) + x_{23}\alpha_3 \cos(wt) + n_2(t) \quad (2.3)$$

$$R_z = x_{31}\alpha_1 \cos(wt) + x_{32}\alpha_2 \cos(wt) + x_{33}\alpha_3 \cos(wt) + n_3(t) \quad .(2.4)$$

where we have include the properties of channel attenuation ,cross polariization, and antenna misalignment in x_{ij}.

For convenience, we rewrite the equations in the matrix form as follows:

$$\underline{R} = \underline{\underline{X}}\,\underline{A}\cos(wt) + \underline{n(t)} \quad (3)$$

where

$$\underline{R} = \begin{bmatrix} R_x \\ R_y \\ R_z \end{bmatrix}, \quad \underline{n(t)} = \begin{bmatrix} n_1(t) \\ n_2(t) \\ n_3(t) \end{bmatrix}, \quad \underline{\underline{X}} = \begin{bmatrix} x_{11} & x_{12} & x_{13} \\ x_{21} & x_{22} & x_{23} \\ x_{31} & x_{32} & x_{33} \end{bmatrix}, \quad \underline{A} = \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix}$$

and $n_i(t)$,i=1,2,3, are assumed to be i.i.d Gaussian random process.

To initialize the system properly, we have to characterize the channel. First, a predetermined signal is transmitted from the first antenna, the receiver then receives the signal and estimates the channel parameters x_{11}, x_{21}, and x_{31}. The other parameters, x_{12},x_{22},x_{23},x_{31},x_{32},and x_{33} are all obtained by the similar way. However, the channel matrix may vary slowly. Therefore, we will have to track the channel

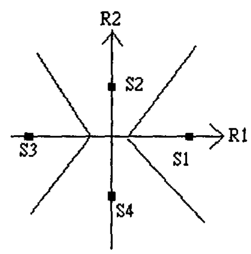

Figure 2 The Receiving Constellation and Decision Boundary

matrix adaptively. For any received symbol, we compute its position in the coordinates as in figure 2, where the meaning of R_1 and R_2 will be defined in equation (9.2) and (9.3). If S_1 is transmitted and correctly received, the receiver can compute the variation of the channel parameters, and then adjust the channel parameters accordingly. Owing to the existence of channel noise, the receiver may make a wrong decision, which implies that the new channel parameters containing errors. Since the channel noise has zero mean, we take the average of several previously received symbols to reduce the noise error.

Performance analysis

For simplicity, we assume that the transmitter tramsmits one of the two symbols , $\vec{S}_a(t)$ and $\vec{S}_b(t)$, which are given by

$$\vec{S}_a(t) = \alpha_1 \cos(wt)\vec{i} + \alpha_2 \cos(wt)\vec{j} + \alpha_3 \cos(wt)\vec{k} \ , \quad (4.1)$$

$$\vec{S}_b(t) = -\alpha_1 \cos(wt)\vec{i} - \alpha_2 \cos(wt)\vec{j} - \alpha_3 \cos(wt)\vec{k} \ . \quad (4.2)$$

With the assumption of equal symbol probability, the optimal decision boundary can be proved to be as follows.

$$(\underline{\underline{X}}\,\underline{A})'\underline{R_d} \underset{S_b}{\overset{S_a}{\gtrless}} 0 \quad (5.1)$$

where

$$\underline{R_d} = \int_0^{T_s} \underline{R}\cos(wt)dt$$

$$= \begin{bmatrix} \int_0^{T_s} x_{11}\alpha_1 \cos^2(wt) + x_{12}\alpha_2 \cos^2(wt) + x_{13}\alpha_3 \cos^2(wt) + n_1(t)\cos(wt)dt \\ \int_0^{T_s} x_{21}\alpha_1 \cos^2(wt) + x_{22}\alpha_2 \cos^2(wt) + x_{23}\alpha_3 \cos^2(wt) + n_2(t)\cos(wt)dt \\ \int_0^{T_s} x_{31}\alpha_1 \cos^2(wt) + x_{32}\alpha_2 \cos^2(wt) + x_{33}\alpha_3 \cos^2(wt) + n_3(t)\cos(wt)dt \end{bmatrix} \quad (5.2)$$

And the bit error rate(BER) can be expressed as follows.

$$BER = Q\left(\sqrt{\frac{T_s}{N_0}\underline{A}'\underline{\underline{X}}'\underline{\underline{X}}\underline{A}}\right) \quad (6)$$

where Q(.) denotes the Q function.

To minimize BER, we should maximize the following equation.

$$\varphi(\underline{A}) = \underline{A}'\underline{\underline{X}}'\underline{\underline{X}}\underline{A} \quad (7)$$

Differentiating this equation, we can obtain the following equation.

$$\underline{A}'\underline{\underline{X}}'\underline{\underline{X}}\underline{A} = \lambda A'\underline{A} \quad (8)$$

Therefore, the eigenvector corresponding to the maximal eigenvalue λ should be found to minimize BER. Since X^tX is positive semidefinite, the eigenvectors corresponding to different eigenvalues are orthogonal and the eigenvalues are nonnegative. That is, we have three mutually orthogonal eigenvectors. And we can construct our symbols from the linear combination of these three eigenvectors.

Assume A_i is the unit eigenvector corresponding to λ_i and R_i is the vector form of the receiving signal when A_i is transmitted. It should be noted that when we say A_i is transmitted, we mean that the following signal $a_i(t)$ is transmitted.

$$\begin{aligned}\vec{a}_i(t) &= a_{i1}\cos(wt)\vec{i} + a_{i2}\cos(wt)\vec{j} + a_{i3}\cos(wt)\vec{k} \\ &= \underline{A_i}'[\vec{i} \quad \vec{j} \quad \vec{k}]'\cos(wt) \quad (9.1)\end{aligned}$$

$$\underline{A_i}' = [a_{i1} \quad a_{i2} \quad a_{i3}]$$

where

$i = 1,2,3$

Similarly, we can write the vector form of the receiving signal as follows:

$$\underline{R_1} = \underline{\underline{X}}\underline{A_1} \quad (9.2)$$

$$\underline{R_2} = \underline{\underline{X}}\underline{A_2} \quad (9.3)$$

Based on (9.2) and (9.3), we have

$$\underline{R_1}' * \underline{R_2} = \underline{A_1}'\underline{\underline{X}}'\underline{\underline{X}}\underline{A_2} = A_1' * \lambda_2\underline{A_2} = 0 \quad (10)$$

It means that the receiving signals are also orthogonal. Now, we can design the symbols by properly choosing the values of a_1,a_2,and a_3. As an example we consider the situation when we want to have a symbol set containing four symbols. The three eigenvectors are mutually orthogonal, which can be normalized and used as the bases of the three

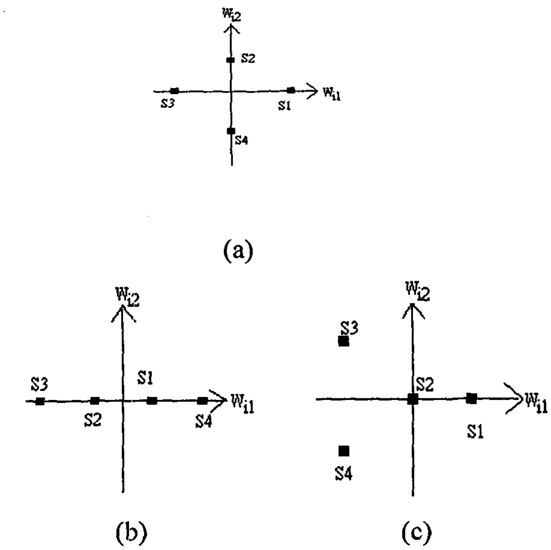

Figure 3 Symbol Constellations

dimensional signal space. Therefore, the symbols can be represented by the linear combination of the three unit eigenvectors. The transmitted symbols and their symbol energy are given as follows.

$$\vec{S}_i(t) = \sum_{j=1}^{3} w_{ij}\vec{a}_j(t) \quad (11.1)$$

where $i = 1,2,3,4$

$$E_{ti} = \sum_{j=1}^{3} w_{ij}^{2} \quad (11.2)$$

$$E_{s,ave} = 2E_{b,ave} = \frac{1}{4}\sum_{j=1}^{4} E_{tj} \quad (11.3)$$

where $E_{s,ave}$ and $E_{b,ave}$ are the average symbol energy and the average bit energy respectively.

It is obvious that the symbol error probability is largely dependent on the distance between two symbols, especially the minimal one. Therefore, it is quite reasonable that we maximize the minimal distance ($\min(D_{ij})$) between the symbols to minimize the BER.

The distance between symbols i and j is given by:

$$D_{ij} = (\underline{R_i} - \underline{R_j})' * (\underline{R_i} - \underline{R_j}) \quad (12)$$

where i, j, = 1,2,3,4 and $i \neq j$

Our goal is to find w_{ij} such that $\min(D_{ij})$ is maximized. There are twelve variables to be decided with one constraint. We can start from the three possible constellations shown in Figures 3a, 3b, and 3c,respectively.

We can set $w_{i3}=0 (i=1,2,3)$ for all symbols because λ_3 is relatively quite small, and this means the attenuation along this particular direction is quite severe.

It can be proven that the best choice for the three constellations as follows.

constellation 1:

$$\underline{W_{con\,1}} = [w_{ij}]_{4\times3} = \begin{bmatrix} \sqrt{\frac{3(\lambda_2/\lambda_1)}{1+3(\lambda_2/\lambda_1)}} & 0 & 0 \\ 0 & \sqrt{\frac{1}{1+3(\lambda_2/\lambda_1)}} & 0 \\ -\sqrt{\frac{3(\lambda_2/\lambda_1)}{1+3(\lambda_2/\lambda_1)}} & 0 & 0 \\ 0 & -\sqrt{\frac{1}{1+3(\lambda_2/\lambda_1)}} & 0 \end{bmatrix} \tag{13}$$

constellation 2:

$$\underline{W_{con\,2}} = [w_{ij}]_{4\times3} = \begin{bmatrix} \sqrt{\frac{1}{10}} & 0 & 0 \\ -\sqrt{\frac{1}{10}} & 0 & 0 \\ 0 & -\sqrt{\frac{9}{10}} & 0 \\ 0 & \sqrt{\frac{9}{10}} & 0 \end{bmatrix} \tag{14}$$

constellation 3:

$$\underline{W_{con\,3}} = [w_{ij}]_{4\times3} = \begin{bmatrix} \sqrt{\frac{4(\lambda_2/\lambda_1)}{1+5(\lambda_2/\lambda_1)}} & 0 & 0 \\ 0 & 0 & 0 \\ -\sqrt{\frac{3(\lambda_2/\lambda_1)}{1+5(\lambda_2/\lambda_1)}} & \sqrt{\frac{1}{1+5(\lambda_2/\lambda_1)}} & 0 \\ -\sqrt{\frac{3(\lambda_2/\lambda_1)}{1+5(\lambda_2/\lambda_1)}} & -\sqrt{\frac{1}{1+5(\lambda_2/\lambda_1)}} & 0 \end{bmatrix} \tag{15}$$

Then, the minimal distance for Constellations 1, 2,and 3 are given as follows:

$$L_{1,\min}{}^2 = \min(D_{ij}) = \frac{3(\lambda_2/\lambda_1)}{1+5(\lambda_2/\lambda_1)}.\lambda_1 \tag{16.1}$$

$$L_{2,\min}{}^2 = \min(D_{ij}) = \frac{2}{5}.\lambda_1 \tag{16.2}$$

and

$$L_{3,\min}{}^2 = \min(D_{ij}) = \frac{4(\lambda_2/\lambda_1)}{1+5(\lambda_2/\lambda_1)}\lambda_1 \tag{16.3}$$

We observed that $L_{1,\min}$ is always larger than $L_{3,\min}$, and $L_{1,\min}$ is smaller than $L_{2,\min}$ only when (λ_2/λ_1) is smaller than 1/7. Therefore, the first constellation is always better than the third one. And the first one is better than the second one when (λ_2/λ_1) is larger than 1/7. Based on the result of computer search , we observed that when $(\lambda_2/\lambda_1) > 1/7$ the first constellation is the best choice otherwise the second one is the best.

The decision boundary of Constellation one is given in Figure 2.When the signals of Constellation one is transmitted, the average bit error rate can be found as follows. Let $P_{ei->j}$ denote the probability that Symbol i was transmitted but Symbol j is chosen at the re-

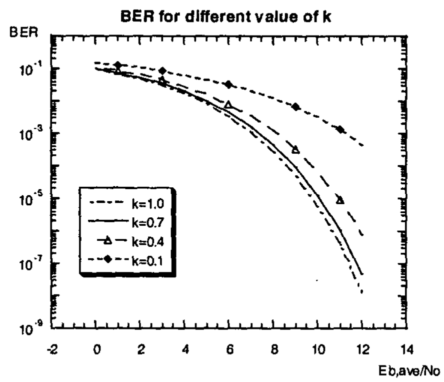

Figure 4. Ber performance for Constellation 1

ceiver. The different symbol errors and average BER are given as follows :

$$P_{e1\to2} = \int_0^{\infty}\int_{-(\frac{a}{2}+\frac{\sqrt{k}b}{a}(y-\frac{b}{2}))}^{\frac{a}{2}+\frac{\sqrt{k}b}{a}(y-\frac{b}{2})} \frac{1}{2\pi\sigma} e^{-\frac{(x-a)^2+y^2}{2\sigma^2}} dxdy \tag{17.1}$$

$$P_{e1\to3} = \int_{-\infty}^{-(\frac{a^2-kb^2}{2a})}\int_{-(\frac{\sqrt{k}b}{2}+\frac{a}{\sqrt{k}b}(-x-\frac{a}{2}))}^{\frac{\sqrt{k}b}{2}+\frac{a}{\sqrt{k}b}(-x-\frac{a}{2})} \frac{1}{2\pi\sigma} e^{-\frac{(x-a)^2+y^2}{2\sigma^2}} dydx \tag{17.2}$$

$$P_{e1\to4} = P_{e1\to2}$$

$$P_{e2\to3} = P_{e2\to1} = \int_{\frac{a^2-kb^2}{2a}}^{\infty}\int_{-(\frac{\sqrt{k}b}{2}+\frac{a}{\sqrt{k}b}(x-\frac{a}{2}))}^{\frac{\sqrt{k}b}{2}+\frac{a}{\sqrt{k}b}(x-\frac{a}{2})} \frac{1}{2\pi\sigma} e^{-\frac{x^2+(y-\sqrt{k}b)^2}{2\sigma^2}} dydx \tag{17.3}$$

$$P_{e2\to4} = P_{e4\to2} = \int_0^{\infty}\int_{-(\frac{a}{2}+\frac{\sqrt{k}b}{a}(y-\frac{b}{2}))}^{\frac{a}{2}+\frac{\sqrt{k}b}{a}(y-\frac{b}{2})} \frac{1}{2\pi\sigma} e^{-\frac{x^2+(y+\sqrt{k}b)^2}{2\sigma^2}} dxdy \tag{17.4}$$

and

$$BER_{ave} = \frac{1}{2}(P_{e2\to1} + P_{e2\to4} + P_{e1\to2} + P_{e1\to3}) \tag{17.5}$$

where

$$a = \sqrt{\frac{3(\lambda_2/\lambda_1)}{1+3(\lambda_2/\lambda_1)}}$$

$$b = \sqrt{\frac{1}{1+3(\lambda_2/\lambda_1)}}$$

In Figure 4 we plot the average bit error rate versus average Eb/No for different values of k, where k equals to λ_2/λ_1. Here, we have set λ_1 to 1 and λ_2 to $k\lambda_1$. This means that the attenuation constant is unity of the direction of $\underline{A_1}$. When k=1, the two transmitting direction will have the same attenuation. Therefore, at this time, the BER performance is the same as the traditional one for BPSK. However, we have twice the capacity of the tranditional BPSK since we have used two different polarized wave for the transmission. It should be noted that the Eb is not the receiving bit energy, but the transmitting bit energy under normalized attenuation condition $\lambda_1=1$ because even the same symbol energy is transmitted at the transmitter, the received symbol energy may be different as a result of different attenuation in different direction. In Figure 5, we show the effect of antenna tilt for the traditional single polarized wave system. In our system, since we have antennas that can receive the signals in different polarizations and combine them, antenna tilt will not affect the system performance.

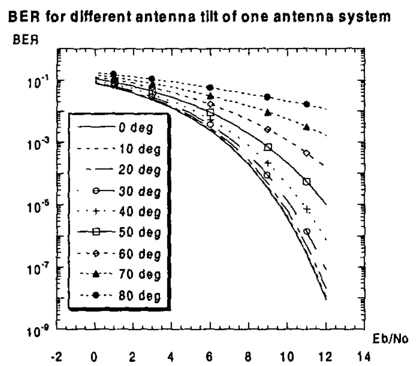

Figure 5. BER degradation for traditional single polarized wave system

V. Conclusion

The proposed scheme employs three orthogonal antennas and utilizes the polarized waves carrying information to increase the spectrum utilization efficiency. In general, when the electromagnetic waves propagate, the component along the propagation direction is very small. So practically the system utilizes two polarized waves say vertical and horizontal waves. The transmission capacity is doubled comparing with the conventional single polarized wave system. Because the proposed scheme has the mechanism to combine the signals of different polarizations, the antenna misalignment can be ignored. When cross polarization occurs, the system can adjust the pattern of the transmission symbols to reduce the effect of cross polarization. Therefore, the performance can be maintained at certain level.It is expected that the scheme may be applied to ka band satellite communication systems and land multipoint distrubution systems.

Acknowledgement

The author wish to thank the National Science Council, R.O.C for supporting this work under grant NSC-88-2213-E-002-081

References

[1] William C.Y.Lee, "Mobile Communications Design Fundamentals", Chap11, New York,Wiley .

[2] D. C. Cox, "Antenna diversity performance in mitigating the effects of portable radiotelephone orientation and multipath propagation," IEEE Transaction on Communication, vol. 31,no. 5, pp. 620-628, May 1983

[3] W.C.Y. Lee and Y.S. Yeh, "Polarization diversity system for mobile radio, " IEEE Transaction on Communication, vol. 20, no. 10, pp. 912-913, Oct. 1972

[4] C. E. Hendrix, G. Kulon, C. S. Anderson, M. A. Heinze, "Multigigabit transmission through rain in a dual polarization frequency reuse system: an experimental study." IEEE Transactions on Communications v 41, no. 12, p 1830-1837, Dec, 1993

[5] S. Benedetto, "Theory of Polarization Shift Keying Modulation",IEEE Transaction on Communication, vol 40, NO. 4, April 1992.

[6] A. Rocha, "Two XPD frequency scaling models using quasi-physical parameters to characterize earth satellite propagation channel",in IEEE Antennas and Propagation Society, AP-S International Symposium (Digest) 4,Baltimore Maryland, p 2548-2551,1997

[7] A. william Norris, M. F. Wazowicz, "Cross-Polarization Coupling Measured for 800 MHz Radio Transmission In and Around Houses and Large Buildings",IEEE Transactions on Antennas and Propagation, vol. 34, no. 1, January 1986

[8] Rocha, Armando "Two XPD frequency scaling models using quasi-physical parameters to characterize earth satellite propagation channel.", IEEE Antennas and Propagation Society, AP-S International Symposium (Digest) 4,Baltimore Maryland, pp 2548-2551,1997

[9] H. V. Bazak, "Simple depolarization compensator for a very wideband communications links - an experimental evaluation.," IEEE Transactions on Communications vol. 42, no. 5, pp. 2073-2077,May, 1994