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Reverse Link Performance Improvement for Wideband OFDM Using Alamouti Coded Heterogeneous Polarization Antennas

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SUMMARY The combination of OFDM and multiple antennas in either the transmitter or receiver is attractive to increase a diversity gain. However, multiple antennas system requires an antenna separation of 5–10 λ to keep the correlation coefficient below 0.7 for the space diversity, so this may be difficult to implement in a mobile station with high mobility. Recently, the polarization transmit diversity is considered in a mobile station. However, polarization transmit diversity requires twice transmit powers to compare with the conventional transmit diversity, since only vertically polar antenna cannot receive the horizontal signal components. In this paper, we express the cross correlation of each polarization antenna and the cross polarization discrimination (XPD) of multiple polarization antennas with simple model, and we propose an wideband OFDM using Alamouti coded heterogeneous polarization antennas for reducing the previous problem. From the simulated results, the proposed system shows better BER performance than that of the conventional STBC/OFDM.
key words: *OFDM, STBC, polarization, XPD*

1. Introduction

The growth of the telecommunications industry coupled with increasing demand for a wide variety of high rate multimedia services has placed an extreme strain on the bandwidth. Japanese government adopted E-Japan priority plan in early 2001, including an explicit goal for wireless communications, to create an IPv6-based high-speed radio access environment and to enable seamless mobile communication services. MIRAI (Multimedia Integrated network by Radio Access Innovation), a project that the National Institute of Information and Communications Technology (NICT) are working on, is one of the most famous Japanese national projects of the E-Japan plan for the seamless integration of heterogeneous wireless systems [1]. This project proposed several ultra high-speed radio access protocols such as wireless LAN and ITS using a millimeter-wave [2]–[4]. In wireless systems, signals are usually impaired by fading and multi-path delay phenomenon. In such channels, severe fading of the signal amplitude and inter-symbol-interference (ISI) due to the frequency selective fading cause an unacceptable degradation of error performance. The combination of OFDM and multiple antennas in either the transmitter or receiver is attractive to increase the system performance, since this combination can eliminate ISI by inserting the guard interval longer than the delay spread and can increase the diversity order to use multiple antennas [5], [6]. Multiple antennas based systems achieve a significant diversity gain as long as the correlation coefficient is less than approximately 0.7 [7]. Multiple antennas system requires an antenna separation of 5–10 λ to keep the correlation coefficient below 0.7 [8]. Therefore, this is expensive to implement in a mobile station. In general, the reflection properties that apply to each polarization component are different. This gives rise to different random phase changes for each component. Even if the transmitted polarization is truly vertical, after a random number of reflections it is conceivable that the received polarization along with the random phase of each observation will be uncorrelated. This is so called polarization, as a source of diversity, which has been studied as early as 1972 but has not become popular until recently [9]. When we consider the polarization, we can take a diversity without an antenna separation of 5–10 λ. Furthermore, polarization device technique allows 2 co-located antennas by using a micro-strip techniques. From these reasons, polarization technique is a practical method of attaining diversity [10]. However, the theoretical model of polarization is very difficult and complex. Therefore, we express the cross correlation of each polarization antenna and XPD of multiple polarization antennas with simple model. Moreover, we consider the combination of polarization and a space-time processing. Although the combination of polarization and a space-time processing has been proposed [11], [12], these papers did not consider the basic effect such as XPD. This paper is organized as follows. The polarization transmit diversity is described in Sect. 2, the proposed system is described in Sect. 3. In Sect. 4, we show the simulation results. Finally, the conclusion is given in Sect. 5.

2. Polarization Transmit Diversity

The transmit and reception diversities using multiple antennas are generally considered in a base station, since it is difficult to implement multiple antennas at a mobile station with a high mobility. However, in the reverse link, the system performance is limited by various interferences and multipath fading. To reduce these problems, it is necessary to obtain the diversity without increasing the system and device complexities. Polarization diversity has been attracting considerable interest because the antennas in the scheme can be co-located. Therefore, this is attractive for both network operators, who suffer lack of space for base station sites, and mobile manufacturers who provide mobile terminals with limited size. Since low cross correlation of polarization, po-

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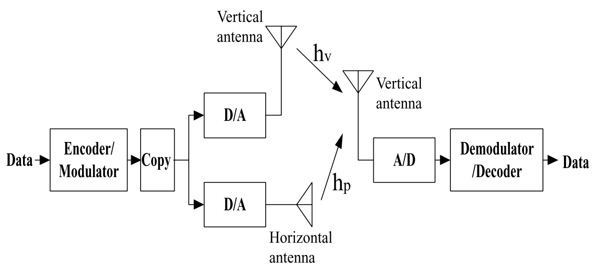

Fig. 1 Conventional polarization system.

larization transmit diversity is attracted [13]. However, polarization transmit diversity has been involved in wireless systems in very simple way for the sake of frequency reuse, etc. For example, typically in satellite systems orthogonally-polarized signals are transmitted in the same bandwidth to realize frequency reuse as shown in Fig. 1 [14]. Although it is effective, such type of simple involvement of polarization enhances the channel capacity simply by doubling power and bandwidth brought by the orthogonal polarization since all polarization channels are independently used. Here we express the cross correlation of each polarization antenna and XPD of multiple polarization antennas.

2.1 Cross Correlation Coefficient of Polarization

Consider the situation where transmit antennas are vertically and horizontally polarizations and the receiver uses two branch polarization diversity antennas as shown in Figs. 2 and 3. Let the receiving antenna system is positioned at the origin, and the angular location of the transmitter is given by θ_v, θ_h, ϕ_v and ϕ_h from the origin. It is assumed that the transmitter and receiver are located in an urban environment and they are sufficiently far away to produce a Rayleigh distributed signal at the receiver. We consider the case where the two diversity antennas at the receiver are oriented at angle ς from the position z-axis as shown in Fig. 3. Without loss of generally, it is assumed that the two receiving antennas lie in the y-z plane. Let the incident electric field at the receiving antennas location is represented by

$$E = E_v + E_h \tag{1}$$
$$E_v = E_{v,1}\hat{u}_{v,1} + E_{v,2}\hat{u}_{v,2}$$
$$E_h = E_{h,1}\hat{u}_{h,1} + E_{h,2}\hat{u}_{h,2}$$

where the unit vectors $\hat{u}_{v,1}$, $\hat{u}_{h,1}$, $\hat{u}_{v,2}$ and $\hat{u}_{h,2}$ are perpendicular to the direction of propagation. The unit vector $\hat{u}_{v,1}$, $\hat{u}_{h,1}$ lie in the horizontal plane and $\hat{u}_{v,2}$, $\hat{u}_{h,2}$ are non-horizontal and titled from the vertical axis by the elevation angles, δ_v, δ_h, respectively. In other words, as shown in Figs. 2 and 3,

$$\hat{u}_{v,1} = -\sin\phi_v \cdot \hat{x} + \cos\phi_v \cdot \hat{y} \tag{2}$$
$$\hat{u}_{h,1} = -\sin\phi_h \cdot \hat{x} + \cos\phi_h \cdot \hat{y} \tag{3}$$
$$\hat{u}_{v,2} = -\sin\delta_v \cdot \cos\phi_v \cdot \hat{x} - \sin\delta_v \cdot \sin\phi_v \cdot \hat{y} + \cos\delta_v \cdot \hat{z} \tag{4}$$
$$\hat{u}_{h,2} = -\sin\delta_h \cdot \cos\phi_h \cdot \hat{x} - \sin\delta_h \cdot \sin\phi_h \cdot \hat{y} + \cos\delta_h \cdot \hat{z} \tag{5}$$

where $\delta_v = \frac{\pi}{2} - \theta_v$, $\delta_h = \frac{\pi}{2} - \theta_h$ are the elevation angles and

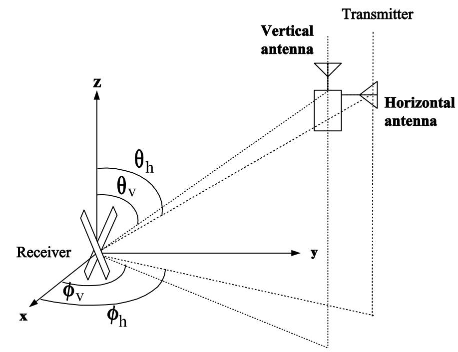

Fig. 2 The transmitter and receiver.

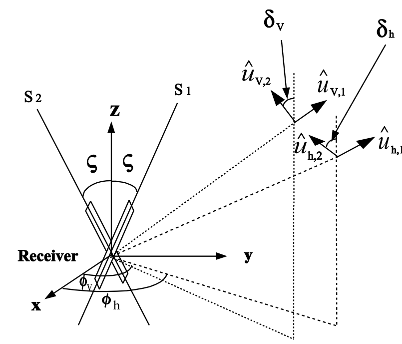

Fig. 3 Incident wave at the receiver.

$\hat{x}$, $\hat{y}$, $\hat{z}$ are unit vectors for the direction of x-axis, y-axis, and z-axis, respectively. Let the unit vectors along the receiving antennas are represented by

$$\hat{s}_1 = \sin\varsigma \cdot \hat{y} + \cos\varsigma \cdot \hat{z} \tag{6}$$
$$\hat{s}_2 = -\sin\varsigma \cdot \hat{y} + \cos\varsigma \cdot \hat{z}. \tag{7}$$

Since the incident electric field at the receiver is Rayleigh distribution, let

$$E_{v,1} = \mathcal{R}_{v,1}\cos(\omega t + \psi_{v,1}) \tag{8}$$
$$E_{h,1} = \mathcal{R}_{h,1}\cos(\omega t + \psi_{h,1}) \tag{9}$$
$$E_{v,2} = \mathcal{R}_{v,2}\cos(\omega t + \psi_{v,2}) \tag{10}$$
$$E_{h,2} = \mathcal{R}_{h,2}\cos(\omega t + \psi_{h,2}) \tag{11}$$

where $\mathcal{R}_{v,1}$, $\mathcal{R}_{h,1}$, $\mathcal{R}_{v,2}$ and $\mathcal{R}_{h,2}$ are independent Rayleigh distributed variable, and $\psi_{v,1}$, $\psi_{h,1}$, $\psi_{v,2}$ and $\psi_{h,2}$ are independent and uniformly distributed. Using Eqs. (1)–(11), we can show that the received signal by antenna S_1 is proportional to

$$S_1 = S_{v,1} + S_{h,1} \tag{12}$$
$$\begin{aligned} S_{v,1} &= E_v \cdot \hat{s}_1 = E_{v,1}\hat{u}_{v,1} \cdot \hat{s}_1 + E_{v,2}\hat{u}_{v,2} \cdot \hat{s}_1 \\ &= E_{v,1}\cos\phi_v \sin\varsigma + E_{v,2}\cos\delta_v \cos\varsigma \\ &\quad - E_{v,2}\sin\delta_v \sin\phi_v \sin\varsigma \\ &= \mathcal{R}_{v,1}\cos\phi_v \sin\varsigma \cos(\omega t + \psi_{v,1}) \\ &\quad + \mathcal{R}_{v,2}[\cos\delta_v \cos\varsigma - \sin\delta_v \sin\phi_v \sin\varsigma] \\ &\quad \cdot \cos(\omega t + \psi_{v,2}) \\ &= (\mathcal{R}_{v,1}\eta_v \cos\psi_{v,1} + \mathcal{R}_{v,2}\tau_v \cos\psi_{v,2})\cos\omega t \end{aligned}$$

$$
\begin{aligned}
&\quad - (\mathcal{R}_{v,1}\eta_v \sin\psi_{v,1} + \mathcal{R}_{v,2}\tau_v \sin\psi_{v,2}) \sin\omega t\\
S_{h,1} &= E_h \cdot \hat{s}_1 = E_{h,1}\hat{u}_{h,1} \cdot \hat{s}_1 + E_{h,2}\hat{u}_{h,2} \cdot \hat{s}_1\\
&= E_{h,1} \cos\phi_h \sin\varsigma + E_{h,2} \cos\delta_h \cos\varsigma\\
&\quad - E_{h,2} \sin\delta_h \sin\phi_h \sin\varsigma\\
&= \mathcal{R}_{h,1} \cos\phi_v \sin\varsigma \cos(\omega t + \psi_{h,1})\\
&\quad + \mathcal{R}_{h,2}[\cos\delta_h \cos\varsigma - \sin\delta_h \sin\phi_h \sin\varsigma]\\
&\quad \cdot \cos(\omega t + \psi_{h,2})\\
&= (\mathcal{R}_{h,1}\eta_h \cos\psi_{h,1} + \mathcal{R}_{h,2}\tau_h \cos\psi_{h,2}) \cos\omega t\\
&\quad - (\mathcal{R}_{h,1}\eta_h \sin\psi_{h,1} + \mathcal{R}_{h,2}\tau_h \sin\psi_{h,2}) \sin\omega t
\end{aligned}
$$

where $\eta_v = \sin\varsigma\cos\phi_v$, $\eta_h = \sin\varsigma\cos\phi_h$, $\tau_v = \cos\delta_v \cos\varsigma - \sin\delta_v \sin\phi_v \sin\varsigma$, $\tau_h = \cos\delta_h \cos\varsigma - \sin\delta_h \sin\phi_h \sin\varsigma$. Similarly, the received signal by antenna S_2 is proportional to

$$
\begin{aligned}
S_2 &= S_{v,2} + S_{h,2} \qquad (13)\\
S_{v,2} &= E_v \cdot \hat{s}_2 = E_{v,1}\hat{u}_{v,1} \cdot \hat{s}_2 + E_{v,2}\hat{u}_{v,2} \cdot \hat{s}_2\\
&= -E_{v,1} \cos\phi_v \sin\varsigma + E_{v,2} \cos\delta_v \cos\varsigma\\
&\quad + E_{v,2} \sin\delta_v \sin\phi_v \sin\varsigma\\
&= -\mathcal{R}_{v,1} \cos\phi_v \sin\varsigma \cos(\omega t + \psi_{v,1})\\
&\quad + \mathcal{R}_{v,2}[\cos\delta_v \cos\varsigma + \sin\delta_v \sin\phi_v \sin\varsigma]\\
&\quad \cdot \cos(\omega t + \psi_{v,2})\\
&= (-\mathcal{R}_{v,1}\eta_v \cos\psi_{v,1} + \mathcal{R}_{v,2}\hat{\tau}_v \cos\psi_{v,2})\\
&\quad \cdot \cos\omega_v t - (-\mathcal{R}_{v,1}\eta_v \sin\psi_{v,1}\\
&\quad + \mathcal{R}_{v,2}\hat{\tau}_v \sin\psi_{v,2}) \sin\omega t\\
S_{h,2} &= E_h \cdot \hat{s}_2 = E_{h,1}\hat{u}_{h,1} \cdot \hat{s}_2 + E_{h,2}\hat{u}_{h,2} \cdot \hat{s}_2\\
&= -E_{h,1} \cos\phi_h \sin\varsigma + E_{h,2} \cos\delta_h \cos\varsigma\\
&\quad + E_{h,2} \sin\delta_h \sin\phi_h \sin\varsigma\\
&= -\mathcal{R}_{h,1} \cos\phi_v \sin\varsigma \cos(\omega t + \psi_{h,1})\\
&\quad + \mathcal{R}_{h,2}[\cos\delta_h \cos\varsigma + \sin\delta_h \sin\phi_h \sin\varsigma]\\
&\quad \cdot \cos(\omega t + \psi_{h,2})\\
&= (-\mathcal{R}_{h,1}\eta_h \cos\psi_{h,1} + \mathcal{R}_{h,2}\hat{\tau}_h \cos\psi_{h,2})\\
&\quad \cdot \cos\omega t - (-\mathcal{R}_{h,1}\eta_h \sin\psi_{h,1}\\
&\quad + \mathcal{R}_{h,2}\hat{\tau}_h \sin\psi_{h,2}) \sin\omega t
\end{aligned}
$$

where $\hat{\tau}_v = \cos\delta_v \cos\varsigma + \sin\delta_v \sin\phi_v \sin\varsigma$, $\hat{\tau}_h = \cos\delta_h \cos\varsigma + \sin\delta_h \sin\phi_h \sin\varsigma$. The amplitudes of the received vertical polarization component signals by S_1 and S_2 are therefore proportional to

$$
\begin{aligned}
\Gamma_{v,1} &= [(\mathcal{R}_{v,1}\eta_v \cos\psi_{v,1} + \mathcal{R}_{v,2}\tau_v \cos\psi_{v,2})^2 \qquad (14)\\
&\quad + (\mathcal{R}_{v,1}\eta_v \sin\psi_{v,1} + \mathcal{R}_{v,2}\tau_v \sin\psi_{v,2})^2]^{1/2}\\
&= [\mathcal{R}_{v,1}^2\eta_v^2 + \mathcal{R}_{v,2}^2\tau_v^2 + 2\mathcal{R}_{v,1}\mathcal{R}_{v,2}\eta_v\tau_v\\
&\quad \cdot \cos(\psi_{v,1} - \psi_{v,2})]^{1/2}\\
\Gamma_{v,2} &= [\mathcal{R}_{v,1}^2\eta_v^2 + \mathcal{R}_{v,2}^2\hat{\tau}_v^2 - 2\mathcal{R}_{v,1}\mathcal{R}_{v,2}\eta_v\hat{\tau}_v\\
&\quad \cdot \cos(\psi_{v,1} - \psi_{v,2})]^{1/2}.
\end{aligned}
$$

As quoted in [15], [16], the vertical polarization component correlation coefficient ρ_v is given by

$$\rho_v = \frac{\langle\Gamma_{v,1}^2 \cdot \Gamma_{v,2}^2\rangle - \langle\Gamma_{v,1}^2\rangle\langle\Gamma_{v,2}^2\rangle}{[(\langle\Gamma_{v1}^4\rangle - \langle\Gamma_{v1}^2\rangle^2)(\langle\Gamma_{v,2}^4\rangle - \langle\Gamma_{v,2}^2\rangle^2)]^{1/2}}. \qquad (15)$$

Using the assumption that $\mathcal{R}_{v,1}$ and $\mathcal{R}_{v,2}$ follow a Rayleigh distribute, $\langle\mathcal{R}_{v,1}^4\rangle = 2\langle\mathcal{R}_{v,1}^2\rangle^2$ and $\langle\mathcal{R}_{v,2}^4\rangle = 2\langle\mathcal{R}_{v,2}^2\rangle^2$ [17], and let us denote the cross polarization of vertical polarization component by $X_v = \langle\mathcal{R}_{v,2}^2\rangle/\langle\mathcal{R}_{v,1}^2\rangle$. Therefore,

$$\rho_v = \frac{(\eta_v^2 - \tau_v\hat{\tau}_v X_v)^2}{[(\eta_v^2 + X_v\tau_v^2)(\eta_v^2 + X_v\hat{\tau}_v^2)]}. \qquad (16)$$

Similarly, the horizontal polarization component correlation coefficient ρ_h is

$$\rho_h = \frac{(\eta_h^2 - \tau_h\hat{\tau}_h X_h)^2}{[(\eta_h^2 + X_h\tau_h^2)(\eta_h^2 + X_h\hat{\tau}_h^2)]}. \qquad (17)$$

Using Eqs. (16) and (17), we can calculate the cross correlation of polarization reception. If the received antennas are oriented at 45° from the vertical axis, an elevation angle as small as 30° causes a very desirable level of correlation coefficient only 0.25 at broadside incidence $\phi = 0°$ and less than 0.7 for 75 % of azimuthal range at the receiver. In this paper, we consider the correlation coefficient of polarization reception as 0.2.

2.2 XPD

Using Eq. (14), the average received signal level at the receiving antennas is less than the signal level that would be received by a vertically polarized antenna. The average received signal from the vertical polarization transmit antenna by a vertically polarized receiving antenna is $\langle\Gamma_{v,0}^2\rangle = \langle\mathcal{R}_{v,2}^2\rangle\cos\delta_v$ whereas the average received signal level by the polarization diversity antenna S_1 is $\langle\Gamma_{v,1}^2\rangle$. Thus, the ratio of these two is

$$
\begin{aligned}
L_{v,1} &= \frac{\langle\Gamma_{v,1}^2\rangle}{\langle\Gamma_{v,0}^2\rangle} = \frac{\langle\mathcal{R}_{v,1}^2\eta_v^2 + \mathcal{R}_{v,2}^2\tau_v^2\rangle}{\langle\mathcal{R}_{v,2}^2\rangle\cos\delta_v} \qquad (18)\\
&= \frac{\langle\mathcal{R}_{v,1}^2\rangle\eta_v^2}{\langle\mathcal{R}_{v,2}^2\rangle\cos\delta_v} + \frac{\tau_v^2}{\cos\delta_v}\\
&= \frac{\eta_v^2}{\cos\delta_v X_v} + \frac{\tau_v^2}{\cos\delta_v}.
\end{aligned}
$$

Similarly, the average received signal level by the polarization diversity antenna S_2 is $\langle\Gamma_{v,2}^2\rangle$. Thus,

$$
\begin{aligned}
L_{v,2} &= \frac{\langle\Gamma_{v,2}^2\rangle}{\langle\Gamma_{v,0}^2\rangle} = \frac{\langle\mathcal{R}_{v,1}^2\eta_v^2 + \mathcal{R}_{v,2}^2\hat{\tau}_v{}^2\rangle}{\langle\mathcal{R}_{v,2}^2\rangle\cos\delta_v} \qquad (19)\\
&= \frac{\langle\mathcal{R}_{v,1}^2\rangle\eta_v^2}{\langle\mathcal{R}_{v,2}^2\rangle\cos\delta_v} + \frac{\hat{\tau}_v{}^2}{\cos\delta_v}\\
&= \frac{\eta_v^2}{\cos\delta_v X_v} + \frac{\hat{\tau}_v{}^2}{\cos\delta_v}.
\end{aligned}
$$

From Figs. 4 and 5, the decrease in correlation coefficient occurs at the cost of decreased signal level in one branch (between −4 dB and −23 dB for S_1) relative to that received by a vertical antenna. In the horizontally and vertically polarization antennas, XPD value vary between 5–15 dB depending on the environment [18].

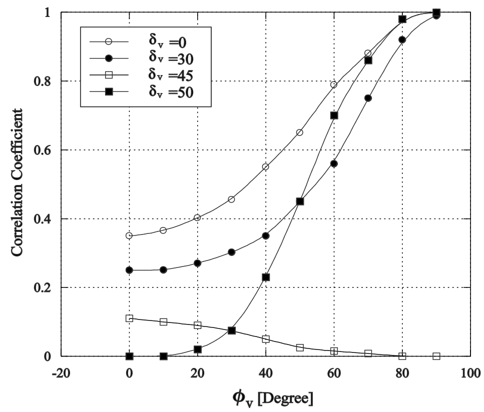

Fig. 4 The correlation coefficient of polarization for $\varsigma = 45°$.

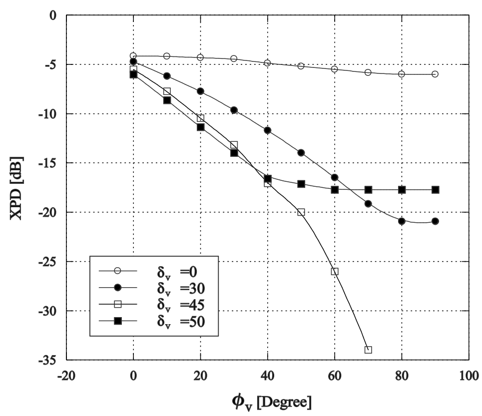

Fig. 5 The XPD of polarization for $\varsigma = 45°$.

3. Proposed System

In this section, we consider an wideband OFDM using Alamouti coded heterogeneous polarization antennas for increasing the system performance. Alamouti code is the simple transmit diversity technique using two transmit antennas. This scheme requires the orthogonality property as

$$X^H X = (|s_1|^2 + |s_2|^2 + \cdots + |s_i|^2)\mathbf{I} \tag{20}$$

where superscript H, X^H, $\mathbf{I}$, and s_i are the complex conjugate transpose, the transmission matrix, the identity matrix, and the transmitted signal and the element of X, respectively. For 2-branch space-time Tx diversity, the transmission matrix using famous Alamouti's scheme is $X = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}$. The information symbols can be decoded without a reduction of the transmission rate and the complex signal processing by using orthogonality property and channel state information. Table 1 shows the transmitted signals at each transmit antenna in the STBC. At time t, the signals s_v, s_h are transmitted simultaneously from the transmit polarization antenna one (vertically polarization antenna) and two (horizontally polarization antenna), respectively. At the time $t+T$, $-s_h^*$, s_v^* are transmitted simultaneously vertically and horizontally polarization antennas, respectively. The channel coefficients of the four different propagation channels $h_{v,1}$, $h_{v,2}$, $h_{h,1}$, and $h_{h,2}$ are assumed constant over successive symbols s_v and s_h as

Table 1 Transmitted signals at two transmit antennas (Tx).

	time t	time t+T
Vertical antenna	S_v	$-S_h^*$
Horizontal antenna	S_h	S_v^*

Table 2 Received signals at receive antennas (Rx).

	time t	time t+T
Rx1	$r_{1,v}$	$r_{1,h}$
Rx2	$r_{2,v}$	$r_{2,h}$

$$\begin{aligned}
h_{v,1}(t) &= h_{v,1}(t+T) = h_{v,1} = \alpha_{v,1}e^{j\epsilon_{v,1}} \\
h_{v,2}(t) &= h_{v,2}(t+T) = h_{v,2} = \alpha_{v,2}e^{j\epsilon_{v,2}} \\
h_{h,1}(t) &= h_{h,1}(t+T) = h_{h,1} = \alpha_{h,1}e^{j\epsilon_{h,1}} \\
h_{h,2}(t) &= h_{h,2}(t+T) = h_{h,2} = \alpha_{h,2}e^{j\epsilon_{h,2}}
\end{aligned} \tag{21}$$

where α and ϵ represented the amplitude and phase of the complex channel responses, respectively. The received signal at each received antenna shown in Table 2 can be expressed as

$$\begin{aligned}
r_{1,v} &= h_{v,1}s_v + h_{h,1}s_h + n_{1,v} \\
r_{1,h} &= -h_{v,1}s_h^* + h_{h,1}s_v^* + n_{1,h} \\
r_{2,v} &= h_{v,2}s_v + h_{h,2}s_h + n_{2,v} \\
r_{2,h} &= -h_{v,2}s_h^* + h_{h,2}s_v^* + n_{2,h}
\end{aligned} \tag{22}$$

where $n_{1,v}$, $n_{1,h}$, $n_{2,v}$, and $n_{2,h}$ are AWGN. At the receiver, the combiner forms two combined signals expressed as

$$\begin{aligned}
\hat{s}_v &= h_{v,1}^* r_{1,v} + h_{h,1} r_{1,h}^* + h_{v,2}^* r_{2,v} + h_{h,2} r_{2,h}^* \\
&= (|\alpha_{v,1}|^2 + |\alpha_{h,1}|^2 + |\alpha_{v,2}|^2 + |\alpha_{h,2}|^2)s_v \\
&\quad + h_{v,1}^* n_{1,v} + h_{h,1} n_{1,h}^* + h_{v,2}^* n_{2,v} + h_{h,2} n_{2,h}^* \\
\hat{s}_h &= h_{h,1}^* r_{1,v} - h_{v,1} r_{1,h}^* + h_{h,2}^* r_{2,v} - h_{v,2} r_{2,h}^* \\
&= (|\alpha_{v,1}|^2 + |\alpha_{h,1}|^2 + |\alpha_{v,2}|^2 + |\alpha_{h,2}|^2)s_h \\
&\quad - h_{v,1} n_{1,h}^* + h_{h,1}^* n_{1,v} - h_{v,2} n_{2,h}^* + h_{h,2}^* n_{2,v}.
\end{aligned} \tag{23}$$

At the maximum likelihood detector, the transmitted symbols are estimated by using these combined signals as for one receive antenna. In Alamouti code, the higher diversity gain can be obtained by increasing the number of the receive antennas. Assuming that two transmit and receive polarization antennas are employed, the diversity order is 4 due to Eqs. (16) and (17). However, XPD is very important parameter in accessing the effectiveness of a polarization diversity system. A large imbalance in the received power would render the whole diversity system worthless because the contribution of the weak channel will be negligible in a diversity combining scheme. Now, we consider various types of polarization antenna pairs between transmitter and receiver.

3.1 Case with the Homogeneous Polarization Antenna Pairs between Transmitter and Receiver

When we consider the case with the homogeneous polarization antenna pairs between transmitter and receiver as shown

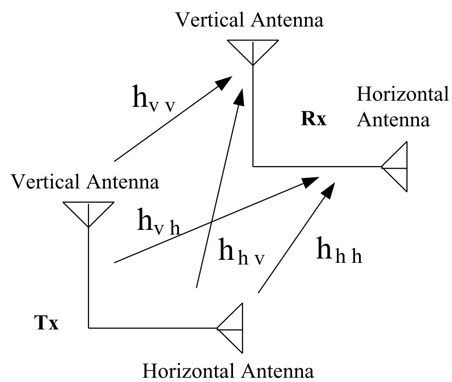

Fig. 6 The homogeneous polarization antenna pairs between transmitter and receiver.

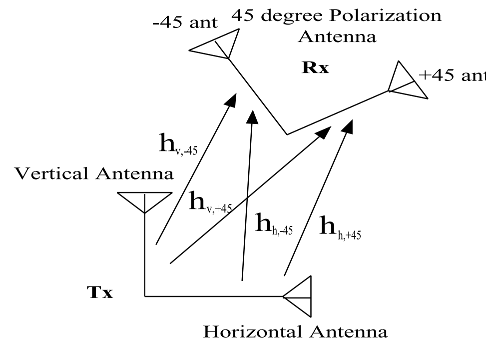

Fig. 7 The heterogeneous polarization antenna pairs between transmitter and receiver.

in Fig. 6, Eq. (23) can be represented by

$$\begin{aligned}\widetilde{s}_v &= h^*_{v,v} r_{v,v} + h_{h,v} r^*_{v,h} + h^*_{v,h} r_{h,v} + h_{h,h} r^*_{v,h} \\ &= (|\alpha_{v,v}|^2 + |\alpha_{h,v}|^2 + |\alpha_{v,h}|^2 + |\alpha_{h,h}|^2) s_v \\ &\quad + h^*_{v,v} n_{v,v} + h_{h,v} n^*_{v,h} + h^*_{v,h} n_{h,v} + h_{h,h} n^*_{h,h} \\ \widetilde{s}_h &= h^*_{h,v} r_{v,v} - h_{v,v} r^*_{v,h} + h^*_{h,h} r_{h,v} - h_{v,h} r^*_{h,h} \\ &= (|\alpha_{v,v}|^2 + |\alpha_{h,v}|^2 + |\alpha_{v,h}|^2 + |\alpha_{h,h}|^2) s_h \\ &\quad - h_{v,v} n^*_{v,h} + h^*_{h,v} n_{v,v} - h_{v,h} n^*_{h,h} + h^*_{h,h} n_{h,v}\end{aligned} \tag{24}$$

where $h_{v,h}$, $r_{h,v}$ are the channel impulse response and received signal from the vertically polarization antenna in transmitter to the horizontally polarization antenna in receiver, respectively. As shown in Eqs. (18) and (19), the homogeneous polarization antenna pairs show different received power such as $\alpha_{v,v} \gg \alpha_{v,h}$ and $\alpha_{h,v} \gg \alpha_{h,h}$ with XPD of 5–15 dB. This imbalance in the received power would render the whole diversity system worthless because the contribution of the weak channel will be negligible in a diversity combining scheme. In such a situation, diversity would be an unnecessary overhead on the receiver and a drain on battery power. Therefore, diversity order as 4 will be degraded due to XPD.

3.2 Case with the Heterogeneous Polarization Antenna Pairs between Transmitter and Receiver

When we consider the case with the heterogeneous polarization antenna pairs between transmitter and receiver as shown in Fig. 7, Eq. (23) can be represented by

$$\begin{aligned}\bar{s}_v &= h^*_{v,-45} r_{-45,v} + h_{h,-45} r^*_{-45,h} \\ &\quad + h^*_{v,+45} r_{+45,v} + h_{h,+45} r^*_{+45,h} \\ &= (|\alpha_{v,-45}|^2 + |\alpha_{h,-45}|^2 + |\alpha_{v,+45}|^2 \\ &\quad + |\alpha_{h,+45}|^2) s_v + h^*_{v,-45} n_{-45,v} \\ &\quad + h_{h,-45} n^*_{-45,h} + h^*_{v,+45} n_{+45,v} \\ &\quad + h_{h,+45} n^*_{+45,h} \\ \bar{s}_h &= h^*_{h,-45} r_{-45,v} - h_{v,-45} r^*_{-45,h} \\ &\quad + h^*_{h,+45} r_{+45,v} - h_{v,+45} r^*_{+45,h} \\ &= (|\alpha_{v,-45}|^2 + |\alpha_{h,-45}|^2 + |\alpha_{v,+45}|^2 \\ &\quad + |\alpha_{h,+45}|^2) s_h - h_{v,-45} n^*_{-45,h} \\ &\quad + h^*_{h,-45} n_{-45,v} - h_{v,+45} n^*_{+45,h} \\ &\quad + h^*_{h,+45} n_{+45,v}\end{aligned} \tag{25}$$

where $h_{v,-45}$, $r_{-45,v}$ are the channel impulse response and received signal from the vertically polarization antenna in transmitter to -45 polarization antenna in receiver, respectively. Since each received antennas show the same inclination angle for transmit polarization branches [16], the average branch powers of the heterogeneous polarization antenna pairs are equalized such as $\alpha_{v,-45} \approx \alpha_{v,+45}$ and $\alpha_{h,-45} \approx \alpha_{h,+45}$. In this case, diversity order is not degraded. In [11], $|h_{0,1}|^2 = |h_{1,0}|^2 = \alpha_f$, and $0 \le \alpha_f \le 1$ is directly related to the XPD. α_f is a measure of the ratio of the received power on each different type diversity branches. Our analysis also considers the same ratio of the received power on each diversity branches. When we consider the case with the heterogeneous polarization antenna pairs between transmitter and receiver as shown in Fig. 8. In this case, the definition of XPD can be expressed as $XPD_{htr,-45} = 10 * \log 10(h_{v,-45}/h_{h,-45})$ or $XPD_{htr,+45} = 10 * \log 10(h_{v,+45}/h_{h,+45})$, where $XPD_{htr,-45}$, $XPD_{htr,+45}$ are the XPD of -45 and +45 antennas, respectively. Moreover, we can easily implement transmit diversity with a micro strip antenna that co-located vertically and horizontally antennas in a mobile station with high mobility.

4. Computer Simulated Results

Figure 8 shows the simulation model of the proposed OFDM system for $N_c = 1024$ sub-carriers. In the transmitter, data streams are serial-to-parallel transformed, and QPSK modulated. Space-time encoder generates the space-time coded symbols. The OFDM time signals are generated by an IFFT and are transmitted over the frequency selective and time variant radio channel after a guard time using cyclic extension has been inserted. In this simulation, we consider the vertically-horizontally polarization antennas in the mobile station and ±45° polarization antennas in the base station, respectively. The transmitted signals are subject to broadband polarization channel propagation as shown in Fig. 9. In this model, $L = 18$ path Rayleigh fadings have exponential shapes with path separation $T_{path} = 140$ nsec. This case

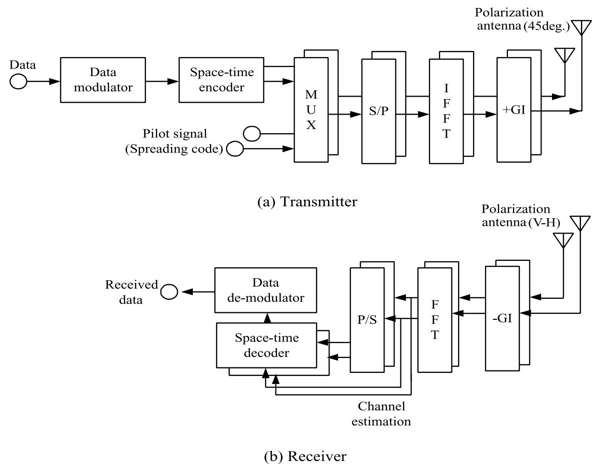

Fig. 8 Proposed system.

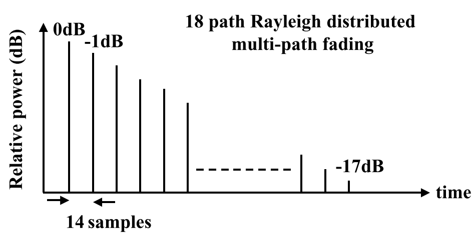

Fig. 9 Channel model.

Table 3 Simulation parameters.

Data modulation	QPSK
Data rate	80 Msample/s
Frame size	12 symbols (N_p=2, N_d=10)
FFT size	1024
Number of carriers	1024
Guard interval	256 sample times
Fading	18 path Rayleigh fading
Doppler frequency	10 Hz
Polarization correlation	0.2
XPD	5,10, and 15 dB
Antennas	Tx, Rx=1 polarization ant. Tx=V-H polar, Rx=V-H or 45 deg. polar

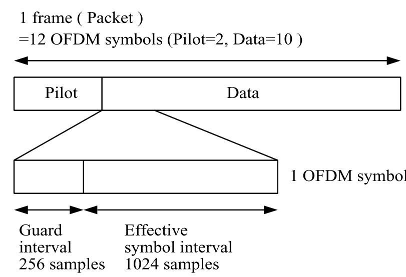

Fig. 10 Packet structure.

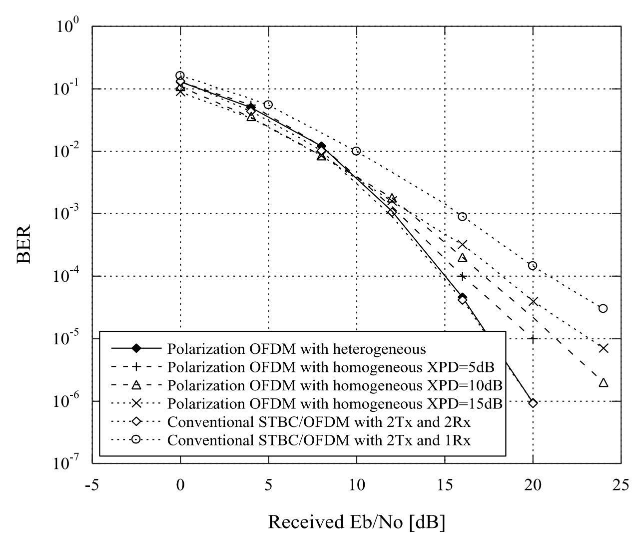

Fig. 11 BER performance of polarization OFDM with heterogeneous polarization antennas and with homogeneous polarization antennas pairs for XPD of 5, 10, 15 dB, the conventional STBC/OFDM with 2Tx and 2Rx, and the conventional STBC/OFDM with 2Tx and 1Rx at Doppler frequency of 10 Hz.

causes a severe frequency selective fading channel. In general, the reflection properties that apply to each polarization component are different. This gives rise to different random phase changes for each component. Even if the transmitted polarization is truly vertical, after a random number of reflections it is conceivable that the received polarization along with the random phase of each observation will be uncorrelated. This assumption has reasonable background by referring to the outline contents of the reference [18]. Therefore, we assumed the independent Rayleigh distribution for each polarization channels. The maximum Doppler frequency is assumed to be 10 Hz. In the receiver, the received signals are serial to parallel converted and N_c parallel sequences are passed to a FFT operator, which converts the signal back to the frequency domain. This frequency domain signal is detected and demodulated by using a space-time decoder. The simulation parameters are listed in Table 3. Figure 10 shows packet structure. Packet consists of 1024 sub-carriers and 12 OFDM symbols (number of pilot signals: $N_p = 2$, number of data: $N_d = 10$). One OFDM symbol duration is 12.8 μsec.

Figure 11 shows the BER performance of polarization OFDM with heterogeneous polarization antennas and with homogeneous polarization antennas pairs for XPD of 5, 10, 15 dB, the conventional STBC/OFDM with 2Tx and 2Rx, and the conventional STBC/OFDM with 2Tx and 1Rx at Doppler frequency of 10 Hz. Polarization diversity with homogeneous means transmitter and receiver used the same polarization antenna type such as vertical and horizontal (V-H) polarization antennas or ±45 degree polarization antennas. In a polarization with homogeneous, XPD is very important parameter in accessing the effectiveness of a polarization diversity system. A large imbalance in the received power would render the whole diversity system worthless because the contribution of the weak channel will be negligible in a diversity combining scheme, so the receiver will continually pick the strongest channel. In such a situation,

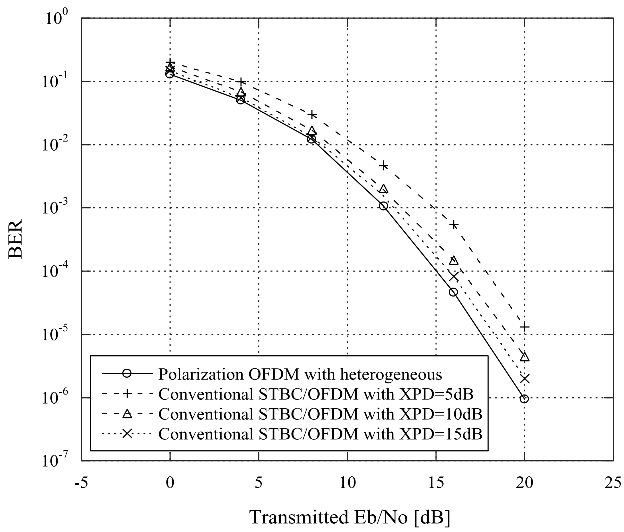

Fig. 12 BER performance of polarization OFDM with heterogeneous polarization antenna, and the conventional STBC/OFDM with XPD=5, 10, 15 dB versus the transmitted E_b/N_0 at Doppler frequency of 10 Hz.

diversity would be an unnecessary overhead on the receiver and a drain on battery power. From this reason, the system performance of polarization OFDM with homogeneous polarization antennas pair for high XPD is degraded with comparison to the polarization OFDM with heterogeneous or the conventional STBC/OFDM with 2Tx and 2Rx. With increasing the XPD, the imbalance is increased. Thus, the BER performance is also degraded.

Figure 12 shows the BER performance of polarization OFDM with heterogeneous polarization antenna, and the conventional STBC/OFDM with XPD=5, 10, 15 dB versus the transmitted E_b/N_0 at Doppler frequency of 10 Hz. In general, received E_b/N_0 is considered as simulation parameter. Here, we consider the transmitted E_b/N_0 to clarify the effect of the XPD. The transmitted E_b/N_0 means the transmit signal to noise ration without considering the propagation loss and the polarization power loss. The traditional STBC/OFDM systems use the vertically polarization antenna. In this case, it is impossible to receive the horizontal signal components. Due to several experiments, the XPD shows about 5–15 dB. Thus, the received powers of the conventional STBC/OFDM are degraded. From this reason, the conventional STBC/OFDM shows worse BER performance than that of the polarization OFDM with heterogeneous for the same transmitted E_b/N_0. Particularly, in low XPD, the power efficiency is degraded compared with that in the high XPD.

5. Conclusion

In this paper, we proposed an Alamouti coded heterogeneous polarization antennas for mitigating the problems of polarization transmit diversity such as transmitted power loss and XPD. The proposed system can improve the system performance about 4 dB compared with the conventional STBC/OFDM with vertically 2Tx and 1RX for the BER of 10^{-3} at the Doppler frequency of 10 Hz. Moreover, the proposed system can obtain good BER with small-transmitted power compared with the conventional STBC/OFDM.

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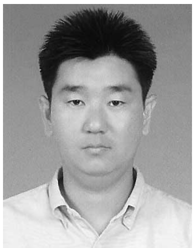

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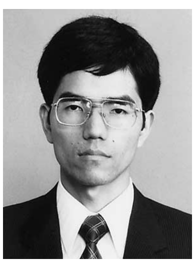

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