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Performance of Closed Loop Polarized MIMO Antenna System Employing Pre-RAKE and Combined Transmit Diversity Techniques in FDD

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***Abstract*—In this paper, an advanced closed loop polarized Multiple-Input Multiple-Output antenna system employing Pre-RAKE and Combined Transmit Diversity techniques "Polarized MIMO Pre-RAKE CTD system" is proposed in Frequency Division Duplex (FDD) mode. The proposed system introduces a significant performance gain without increasing the complexity and the power consumption of the mobile terminal as well as reducing the spatial dimensions of the MIMO system. In this paper, our system will be compared with both the MIMO Pre/Post RAKE system and the Vertical MIMO Pre-RAKE CTD system. The effect of the cross-polarization discrimination (XPD), the envelope correlation (ρ_{env}) and the Co-polarization Power Factor (CPF) on the BER performance will be discussed. Also, the system performance will be investigated under different Feedback Information (FBI) rates. In addition, a performance comparison for the vehicular and the pedestrian environments will be presented.**

***Index Terms*—MIMO, Pre-RAKE, polarization diversity, combined transmit diversity.**

I. Introduction

The combination between MIMO and Pre-RAKE techniques is a strong candidate for the downlink wireless mobile communications due to its capability of capacity enhancement without increasing the complexity and the power consumption of the mobile terminals. The self-interference is acting as a challenge for this combination in case of the vertical MIMO Pre-RAKE systems. In these systems, all the transmitting and the receiving antennas are vertical polarized dipoles. For each transmitting antenna, an adder is used to combine the Pre-RAKEs of the receiving antennas and consequently, the self-interference occurs. In this paper, the polarization diversity technique is presented to mitigate the self-interference as well as reduce the spatial dimensions of the MIMO system where the costly spaced dipoles are replaced by dual polarized antennas. Each dual polarized antenna consists of collocated vertical polarized and horizontal polarized antennas. Many technologies can be used to manufacturer low-cost compact-size dual polarized antennas such as microstrip and planar inverted-F (PIFA) technologies [1], [2]. Another advantage of polarization diversity is its ability to recover the polarization mismatch, which occurs when the polarization of the transmitting antenna and the receiving antenna are different. In wireless communication systems, where the antennas of the mobile units are randomly oriented, polarization receive diversity can collect the signal energy from multiple polarizations, allowing improved performance in a spatially compact array [3], [4].

The characteristics of the polarization diversity have been described by the cross-polarization discrimination (XPD), the Co-polarization Power Factor (CPF) and the envelope correlation (ρ_{env}). The XPD is produced due to the depolarization of the transmitted signal by reflection, diffraction and scattering in the channel [5]. Also, it is defined as the ratio between the cross-polarized signal power to the co-polarized signal power. In the urban and suburban environments, the XPD is normally between -1 and -10 dB, with an average of -6 dB [5], [6]. In dense environments where there is no line of sight, the XPD value approaches to 0 dB. However, the XPD in the rural environments is usually less than -10 dB, between -10 and -18 dB, due to lack of obstacles that couple the signal from one polarization into the other one [5]. Therefore, the XPD is considered as a drawback since it degrades the performance especially in case of dense environments. In this paper, the proposed system can exploit the XPD to improve the performance by using cross-pol Pre-RAKEs in addition to the co-pol Pre-RAKEs in the base station (Node B in UMTS systems). The nature of electromagnetic wave propagation dictates that the polarization orthogonal to the obstacle is attenuated more than the polarization parallel to the obstacle [5], [7]. Considering that buildings are typical obstacles in the wireless channels, the Horizontal Polarization (HPol) is expected to be attenuated more than the Vertical Polarization (VPol). CPF represents the impact of the imbalance in the co-polarized power intensities and it is defined as the ratio between the power of the vertical co-polarized received signal to the power of the horizontal co-polarized received signal. Finally, ρ_{env} represents the envelope correlation between the fadings experienced in the vertical and the horizontal polarization channels. In this paper, the effect of XPD, CPF and ρ_{env} on the BER performance of the proposed system will be examined.

For Single-Input Single-Output (SISO) systems, the Pre/Post RAKE technique is first proposed by Barreto *et al.*

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[8]. In this technique, the simple matched filter will be replaced by a Post-RAKE in the receiving side. The Pre-RAKE weights in the Pre/Post RAKE system are determined in the same way as in case of the Pre-RAKE system. However, the Post-RAKE weights are determined by Maximal Ratio Combining (MRC) to obtain a performance gain from the remaining information in all of the peaks, not only the strongest one. Many algorithms were suggested for adapting the weights of the Pre/Post RAKE to achieve further performance gain. The eigenprecoder algorithm is introduced in [9] and the principal ratio combining (PRC) Pre/Post RAKE, which is a general expansion of the eigenprecoder, has been suggested in [10]. Moreover, the Singular Value Decomposition (SVD) algorithm is presented in [11]. For achieving 10^{-3} BER, the PRC Pre/Post RAKE has about 1.46 dB and 0.15 dB average SNR gain over the Pre-RAKE only and the MRC Pre/Post RAKE, respectively [10]. However, the SVD algorithm can achieve around 2.6 dB gain over the Pre-RAKE only at 10^{-3} BER [11]. Since the Pre-RAKE generates L_t Pre-delayed signals and the channel produces L paths, L_t+L-1 signals with different delays are received. The Post-RAKE should be equipped with L_t+L-1 fingers to combine all of them; when more Pre-RAKE fingers are implemented, more Post-RAKE fingers are required and the complexity of the receiver increases [10].

For Multiple-Input Single-Output (MISO) systems, the Pre/Post RAKE technique was discussed in [9], [12]-[14]. The results showed that as the number of the transmitting antennas increases, the performance gain of the MISO Pre/Post RAKE system over the MISO Pre-RAKE system decreases. Thus, if many transmitting antennas are available, a less hardware demanding system, as the Pre-RAKE only, can achieve a BER similar to the BER's of the more complex structures as the Pre/Post RAKE schemes [12]. This is a considerable reason to preserve the simplicity of the receiver in our proposed system by using only the Pre-RAKE technique.

The Pre/Post RAKE technique is also proposed for MIMO systems in [15]-[17]. Since each receiving antenna in the MIMO Pre/post RAKE system employs its own Post-RAKE circuit, thus the complexity of the system grows with the increase in both the number of the receiving antennas and the number of Pre-RAKE fingers. In this paper, a fair comparison between the proposed polarized MIMO Pre-RAKE CTD system and the MIMO Pre/post RAKE system is performed in complexity and BER performance points of view. As will be shown, the proposed system can achieve a better performance as well as reducing the spatial dimensions of the MIMO system and simplifying the receiver's implementation.

This paper is organized as follows. In Section II, the system model is introduced. The simulation results are illustrated in Section III. Finally, the conclusion is presented in Section IV.

II. System Model

In the proposed Polarized MIMO Pre-RAKE CTD system, all the dual polarized transmitting antennas are used for transmission. The transmitter of the k^{th} user is shown in Fig. 1. The Node B multiplies the k^{th} user's data signal, after QPSK mapping and PN spreading stage, by the complex conjugate of the downlink channel impulse response of all transmitting antennas in each polarization. The estimated channel parameters are provided to the Node B by the FBI message, to be used in the Co-pol and the Cross-pol Pre-RAKEs. It should be noted that these parameters are used during the feedback waiting period till the next update instant of the FBI message. The Co-pol Pre-RAKEs are frequency-separated from the Cross-pol Pre-RAKEs using either nonoverlapped or orthogonal carriers to mitigate the self-interference.

Generally, the orthogonal frequencies should satisfy the following condition [18]:

$$\int_0^{T_c} \cos(\omega_q t).\cos(\omega_j t)dt = 0 \qquad \text{for } q \neq j \tag{1}$$

where T_c is the chip duration, ω_q and ω_j are the q^{th} and j^{th} carrier frequencies, respectively. So, the signal in the j^{th} frequency band does not cause interference in the correlation receiver for the q^{th} frequency band. To achieve this condition, the orthogonal frequencies ω_x are related by [19]:

$$\omega_x = \omega_1 + (x-1)\frac{2\pi}{T_c},\ x = 1,2,3\ldots,X \tag{2}$$

For the same total transmission bandwidth, both nonoverlapped and orthogonal carriers should satisfy the following condition [20]:

$$2X_1 N_1 = (X_2+1)N_2 \tag{3}$$

where N_1 and X_1 are the processing gain and the number of carriers in the nonoverlapping scheme. However, N_2 and X_2 are the processing gain and the number of carriers in the orthogonal scheme. If the two schemes have the same number of carriers (i.e., $X_1 = X_2 = X$). Then, the relation between the processing gains of both schemes will be given by:

$$N_2 = \frac{2X}{X+1} N_1 \tag{4}$$

The signals of the pre-RAKEs associated with the VPol receiving antenna are QPSK modulated using the carrier frequency ω_1 before transmission. However, the carrier frequency ω_2 is used to modulate the signals of the Pre-RAKEs associated to the HPol receiving antenna.

The channel is assumed to be a slowly-varying frequency-selective Rayleigh fading channel with L paths. For a particular downlink channel, the complex impulse response of the channel can be written as:

$$h_{k,m_i,x}(t) = \sum_{l=0}^{L-1} \alpha_{k,m_i,x,l}\ \delta(t-lD) \tag{5}$$

where the subscript i refers to the polarization and i=1 is used for the VPol whereas i=2 is used for the HPol. Also, the subscript x refers to the polarization channel and x=1 is associated to the Co-pol channels while x=2 is associated to the Cross-pol channels. $\alpha_{k,m_i,x,l} = \beta_{k,m_i,x,l} e^{j\gamma_{k,m_i,x,l}}$ is the fading experienced through the l^{th} path of the x^{th} polarization channel between the m^{th} transmitting antenna of the i^{th} polarization and the k^{th} user's mobile terminal. $\beta_{k,m_i,x,l}$ is the Rayleigh–distribution fade envelope (path gain) and it is treated as independent identically distributed (i.i.d.)

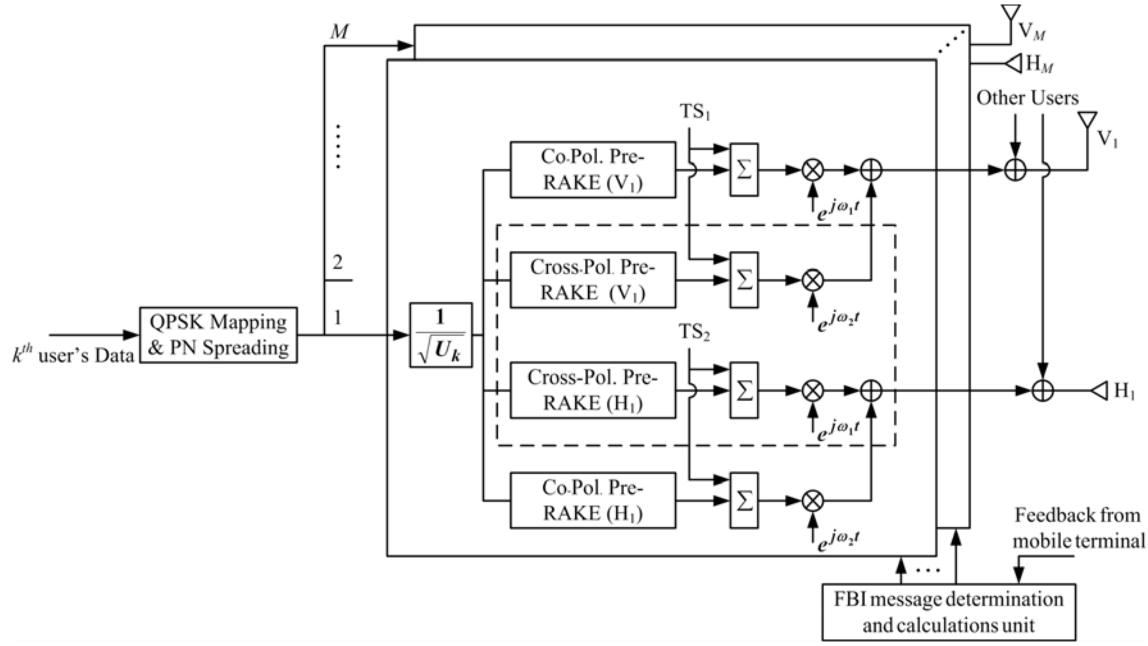

Fig. 1 The Polarized MIMO Pre-RAKE CTD transmitter of the Node B.

Rayleigh random variable. $\gamma_{k,m_i,x,l}$ is i.i.d. uniformaly–distribution phase over [0, 2π]. D is the tapped delay line, which is the delay between the successive paths, assuming that the 1^{st} path has no delay. Finally, $\delta(\cdot)$ is the dirac delta function.

The normalization factor U_k is used to keep the total average transmitted power of the k^{th} user constant and it is expressed as:

$$U_k = \sum_{i=1}^{2}\left(\sum_{m_i=1}^{M}\sum_{x=1}^{X}\sum_{l=0}^{L-1}\left|\alpha_{k,m_i,x,l}\right|^2\right) \tag{6}$$

where M represents the number of the transmitting antennas in each polarization, i.e., M refers to the number of dual polarized transmit antennas. Therefore, the transmitting weights in the Pre-RAKEs can be represented by:

$$B_{k,m_i,x,l} = \frac{\alpha^*_{k,m_i,x,l}}{\sqrt{U_k}} = \frac{\beta_{k,m_i,x,l}\ e^{-j\gamma_{k,m_i,x,l}}}{\sqrt{\sum_{i=1}^{2}\left(\sum_{m_i=1}^{M}\sum_{x=1}^{X}\sum_{l=0}^{L-1}\beta^2_{k,m_i,x,l}\right)}} \tag{7}$$

where $B_{k,m_i,x,l}$ satisfies the constraint:

$$\sum_{i=1}^{2}\sum_{m_i=1}^{M}\sum_{x=1}^{X}\sum_{l=0}^{L-1}\left|B_{k,m_i,x,l}\right|^2 = 1 \tag{8}$$

So, the total average transmitted power of the k^{th} user is kept constant and independent on X, L and M. Hence, the signal transmitted from the m^{th} transmitting antenna in each polarization for the k^{th} user can be represented as:

$$s_{k,m_i}(t) = \sqrt{\frac{P_k}{U_k}}\sum_{x=1}^{X}\sum_{l=0}^{L-1}\beta_{k,m_i,x,L-l-1}\, b_k(t-lD)\, c_k(t-lD)\, e^{j[\omega_x(t-lD)-\gamma_{k,m_i,x,L-l-1}]} \tag{9}$$

where P_k is the transmitted power and $b_k(t)$ is the QPSK mapped sequence whose symbols $\in\{(\pm1\pm j)/\sqrt{2}\}$. Also, $c_k(t)$ is the aperiodic PN spreading sequence with chip duration $T_c=T_s/N$ since N is the processing gain and T_s is the QPSK symbol duration. Moreover, each user has a unique signature sequence $c_k(t)$ different from the other users. ω_x is the carrier frequency associated to either the Co-pol or the Cross-pol Pre-RAKEs.

A synchronous DS/CDMA system is considered for the downlink where K signals are transmitted simultaneously from the Node B to K users. In considering the cross-coupling between the channels, the received signals at the dual polarized receive antenna of the 1^{st} user's mobile terminal can be expressed as:

$$r_{1,v}(t) = \mathrm{Re}\left\{\sum_{k=1}^{K}\sum_{m_1=1}^{M}\sum_{n=0}^{L-1}\beta_{1,m_1,1,n}\,.\,s_{k,m_1}(t-nD)\,e^{j\gamma_{1,m_1,1,n}}\right\} + \mathrm{Re}\left\{\frac{1}{\sqrt{\zeta_{1,h}}}\sum_{k=1}^{K}\sum_{m_2=1}^{M}\sum_{n=0}^{L-1}\beta_{1,m_2,2,n}\,.\,s_{k,m_2}(t-nD)\,e^{j\gamma_{1,m_2,2,n}}\right\} + n_v(t) \tag{10}$$

Similarly:

$$r_{1,h}(t) = \mathrm{Re}\left\{\sum_{k=1}^{K}\sum_{m_2=1}^{M}\sum_{n=0}^{L-1}\beta_{1,m_2,1,n}\,.\,s_{k,m_2}(t-nD)\,e^{j\gamma_{1,m_2,1,n}}\right\} + \mathrm{Re}\left\{\frac{1}{\sqrt{\zeta_{1,v}}}\sum_{k=1}^{K}\sum_{m_1=1}^{M}\sum_{n=0}^{L-1}\beta_{1,m_1,2,n}\,.\,s_{k,m_1}(t-nD)\,e^{j\gamma_{1,m_1,2,n}}\right\} + n_h(t) \tag{11}$$

where $\zeta_{1,v}$ and $\zeta_{1,h}$ are the power intensities of both the vertical and the horizontal cross-Pol signals at the 1^{st} user's mobile station, respectively. n_v(t) and n_h(t) are the Additive White Gaussian Noises (AWGN) at the receiving VPol and HPol antennas of the 1^{st} user, respectively, with zero mean and double-sided power spectral density of $N_o/2$. They represent the thermal noise of the receiver and the undesired interference signals from the other Node Bs in both polarizations.

The receiver implementation of the 1^{st} user's mobile station is shown in Fig. 2. The VPol and the HPol receiving antennas employ different frequencies where $r_{1,v}$(t) is demodulated using the carrier frequency (ω_1) while $r_{1,h}$(t) is demodulated using the carrier frequency (ω_2). Therefore, the interference from the undesired co-pol and cross-pol components transmitted to each receiving antenna will be

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rejected since they lie outside the operating frequency band of this antenna. It can be seen from equations (9), (10) and (11) that the channel output at each polarized receiving antenna includes *2L-1* paths with a strong peak at *t-(L-1)D* which is the desired signal in each polarization. This strong peak is the resultant of both the co-pol and the cross-pol peaks in each polarization. By combining the desired signals of both polarized receiving antennas, a very strong peak is achieved at *t-(L-1)D* and only one matched filter is needed to be tuned to that peak, as shown in Fig. 2. Consequently, a significant performance gain can be accomplished due to the enhancement of the multipath, the polarization and the space combined transmit diversities, while preserving the simplicity of the receiver.

Comparing to the vertical 2x2 MIMO Pre-RAKE CTD system, the proposed system, using only one dual polarized transmit antenna, can reduce the spatial dimensions in both the mobile and the Node B. However, the spatial dimension is reduced only in the mobile terminal in case of using two dual polarized transmit antennas in the Node B.

III. SIMULATION RESULTS

Computer simulations were performed to evaluate the downlink BER performance of the polarized MIMO Pre-RAKE CTD system in FDD mode. In the simulation, UMTS standard is considered where the RF carrier frequency is f_c=2 GHz and the QPSK modulation is applied for the data sequence. Also, the chip rate is R_c=3.84 Mcps and the processing gain is N=32 chips/symbol in case of both the vertical MIMO Pre-RAKE CTD system and the proposed system, without including the cross-pol Pre-RAKEs. To preserve the same transmission bandwidth, N equals 16 chips/symbol for the proposed system using two nonoverlapped carriers. Consequently, from equation (4), N equals 22 chips/symbol in case of using two orthogonal carriers. Both the bit and the chip waveforms are rectangular $\in[-1,1]$. Also, the speed of the mobile is v=120 Km/h. Therefore, the doppler spread is $B_d=v/\lambda$=222 Hz which is much smaller than the transmission bandwidth ($B_d \ll B_s$). Consequently, the channel is considered as a slowly-varying Rayleigh fading channel. In the simulation, the mobile terminal has only one dual polarized antenna whereas the Node B has two dual polarized antennas, spaced far enough from each other to be completely uncorrelated. P_o/P_t (dB) refers to the ratio between the transmitted power from the Node B to the desired user and the total transmitted power from the Node B. So, P_o/P_t is a clear indication about the total number of users (K) that the Node B deals with simultaneously; assuming that all users have the same transmitted power. The simulation is run for K=10 users. The tapped delay line is $D=T_c$ and the FBI rate=1 KHz. Finally, the number of Pre-RAKE fingers is $L_t=L$=3.

The first point is to compare the proposed Polarized MIMO Pre-RAKE CTD system with the advanced MIMO Pre/Post RAKE CTD system, presented in the recent researches [15]-[17]. The performance comparison is performed using the same simulation parameters, presented in paper [15] where N=8, $L_t=L$=2 paths. The Pre/Post RAKE system employs 2x2 MIMO configuration and the number of fingers in each post RAKE is L_r=1. Also, the proposed

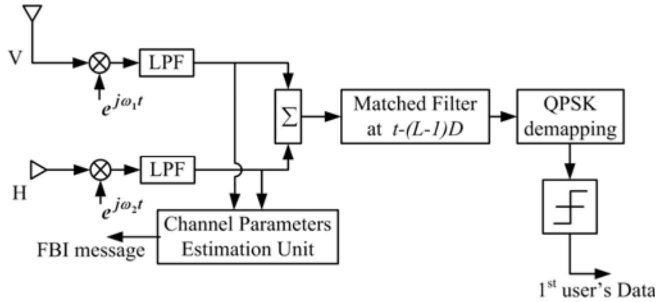

Fig. 2 The Polarized MIMO Pre-RAKE CTD receiver of the 1st user's mobile terminal.

system is evaluated under XPD=0 dB and ρ_{env} =0%, using two dual polarized transmit antennas and one dual polarized receive antenna. Therefore, both systems have the same spatial dimension in the Node B. However, the proposed system reduces the spatial dimension in the mobile terminal as well as simplifying its implementation and reducing its power consumption. In Fig. 3, the BER performance is illustrated in case of $K=3$ users. Both systems can achieve a high performance gain over the 2x1 MISO Pre-RAKE CTD system. Also, the proposed system, using orthogonal carriers, outperforms the Pre/Post RAKE system where the performance improvement approaches 1.5 dB at 10^{-5} BER. Using nonoverlapped carriers, the performance of the proposed system is worse than that in case of Pre/Post RAKE system.

Fig. 4 presents the performance comparison under different number of users in case of E_b/N_o=8 dB. Using orthogonal carriers, the proposed system has much performance gain over the Pre/Post RAKE system. Using nonoverlapped carriers, the performance of the proposed system under small number of users is worse than that in case of the Pre/Post RAKE system. However, as the number of users increases, the performance of the proposed system approaches to the Pre/Post RAKE system till achieving approximately the same performance at K=9. As shown in Fig. 4, the proposed system, using nonoverlapped carriers, outperforms the Pre/Post RAKE system at K=10 users.

Figs. 5 and 6 illustrate the BER performance of the polarized MIMO Pre-RAKE CTD system under multipath fading channel ($L_t=L=3$), using nonoverlapped and orthogonal carriers, respectively. Also, the system performance is evaluated using one and two dual polarized transmit antennas under XPD=0 dB and ρ_{env}=0%. From the figures, many results can be concluded:

- The behavior of the vertical 2x2 MIMO Pre-RAKE CTD system is worse than the 2x1 MISO CTD system. This is due to the self-interference between the Pre-RAKEs transmitting their signals via each transmitting antenna to the receiving antennas in the MIMO system.

- Using one dual polarized transmit antenna, the proposed system can significantly outperform the 2x1 MISO Pre-RAKE system. This is attributed to the polarization diversity gain achieved at the mobile terminal, provided from both the co-pol and cross-pol signals. This polarization diversity gain is higher than the transmit diversity gain of the MISO system since for the polarized MIMO system, more resolved independent fadings are provided to the mobile terminal.

- The proposed system using one dual polarized transmitting antenna can achieve a high performance gain

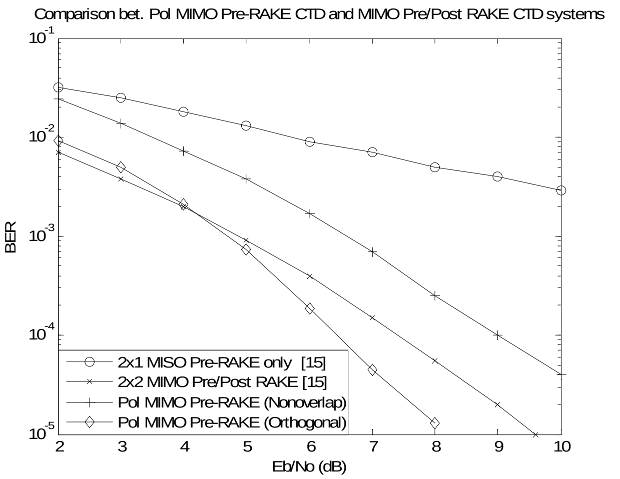

Fig. 3 A performance comparison between the Polarized MIMO Pre-RAKE CTD and the Pre/Post MIMO CTD systems when $K=3$, N=8 and L_t=L=2.

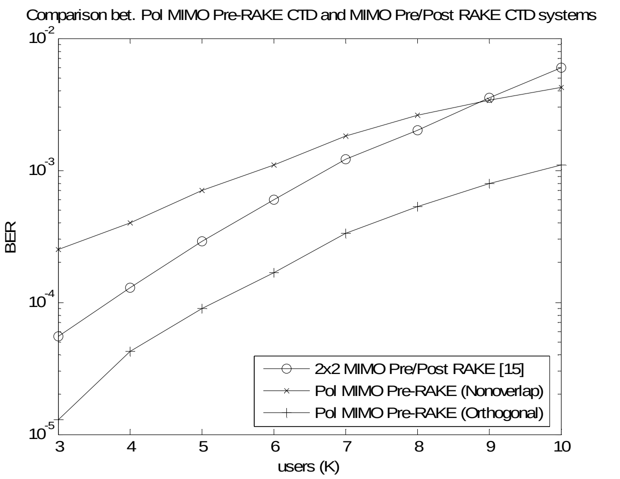

Fig. 4 A performance comparison between the Polarized MIMO Pre-RAKE CTD and the Pre/Post MIMO CTD systems when E_b/N_o=8 dB, N=8 and L_t=L=2.

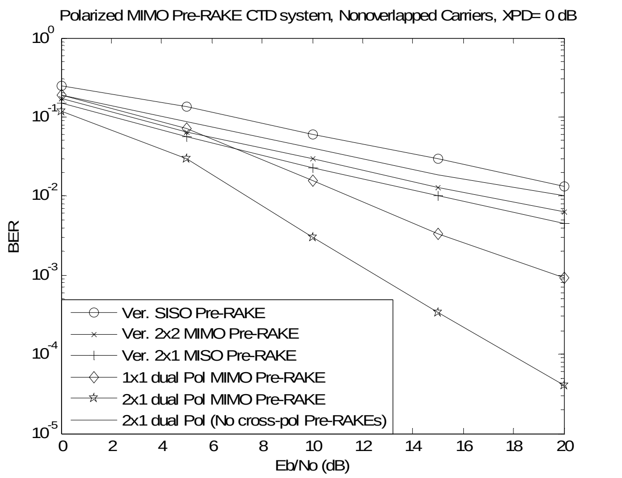

Fig. 5 A performance comparison between the Polarized MIMO Pre-RAKE CTD using nonoverlapped carriers and the Vertical MIMO Pre-RAKE CTD systems when K=10, L_t=L=3 and FBI rate=1 KHz.

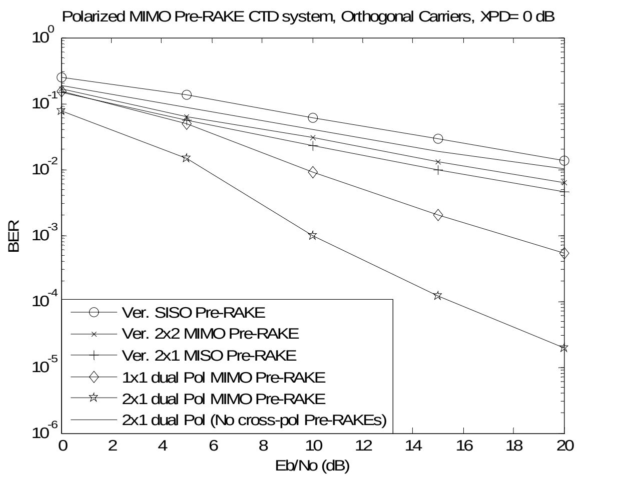

Fig. 6 A performance comparison between the Polarized MIMO Pre-RAKE CTD using orthogonal carriers and the Vertical MIMO Pre-RAKE CTD systems when K=10, L_t=L=3 and FBI rate=1 KHz.

over the vertical 2x2 MIMO system, given the same number of Pre-RAKEs in the Node B. This is caused by the self-interference mitigation presented by the polarization diversity technique.

- The performance of the proposed system improves with the increase in the number of the dual polarized transmitting antennas. This is due to the combined transmit diversity gain achieved in addition to the polarization and the multipath diversities.

- In dense urban and suburban environments, where the XPD approaches to 0 dB, the performance of the proposed system without including the cross-pol Pre-RAKEs is poor. A significant performance gain is achieved by adding the cross-pol Pre-RAKEs in the Node B due to the mitigation of the XPD noise effect and on the contrary, exploiting the cross-pol channels as resolved paths. Therefore, more independent fadings are experienced at the receiver and consequently, the performance improves. It should be noted that the frequency diversity gain, achieved by the frequency separation, can overcome the reduction effect in the bit energy and the processing gain in each carrier's band [18].

- The performance of the proposed system using orthogonal carriers is better than that in case of using nonoverlapped carriers due to the increase in the processing gain.

Fig. 7 examines the performance under different values of XPD and ρ_{env}. As the XPD increases, the performance improves. This is because the proposed system resolves the cross-polarized signals in addition to the co-polarized signals for enhancing the Signal to Interference plus Noise Ratio (SINR). Also, the performance degrades as ρ_{env} increases since the envelope correlation between the fadings experienced in the VPol and the HPol channels becomes stronger with the increase of ρ_{env}.

For slowly-varying channels, different FBI rates result in different BER performance, as shown in Fig. 8. The lower bound of the performance is achieved when the feedback is done every data symbol, i.e., FBI=120 KHz. As the feedback-waiting period increases, which means slower FBI rates, the performance degrades since the transmitting symbols during this period will increase. Therefore, the number of the transmitted symbols, which the downlink channel parameters of the FBI message will not considered as an accurate future prediction about their fading profile, will increase. This causes degradation in the BER

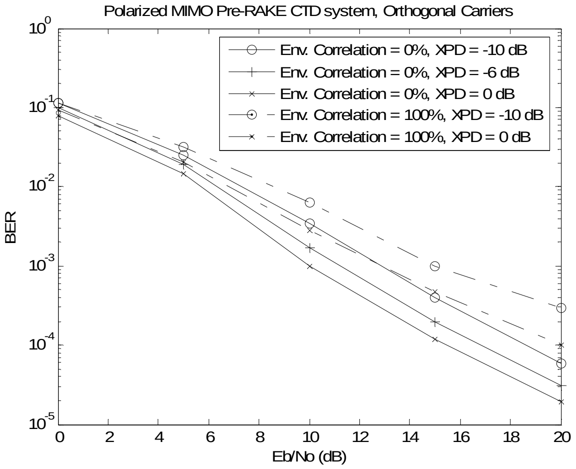

Fig. 7 The performance of the Polarized MIMO Pre-RAKE CTD system using orthogonal carriers under different values of XPD and ρ_{env}.

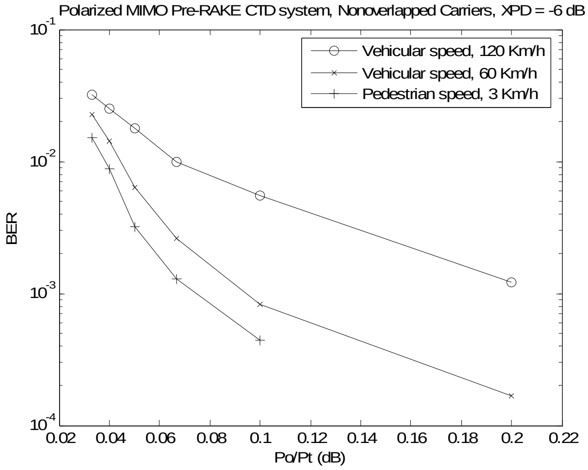

Fig. 9 The performance of the Polarized MIMO Pre-RAKE CTD system using nonoverlapped carriers for both vehicular and pedestrian speeds, E_b/N_o=10 dB.

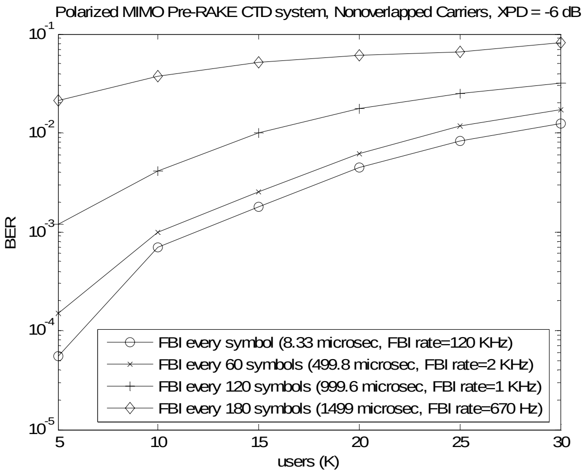

Fig. 8 The performance of the Polarized MIMO Pre-RAKE CTD system using nonoverlapped carriers under different FBI rates, E_b/N_o=10 dB.

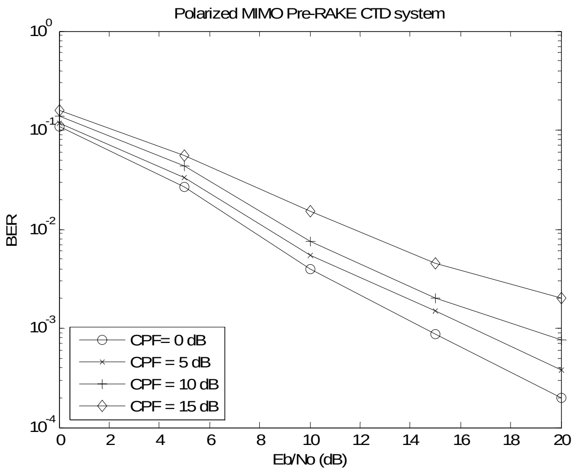

Fig. 10 The impact of the imbalance in the co-pol power intensities (CPF) on the BER performance of the Polarized MIMO Pre-RAKE CTD system.

performance. For certain FBI rate, the performance degrades as the number of users (K) increases due to the Multiple Access Interference (MAI).

All the previous results are simulated for the vehicular speed v=120 Km/h. Now, the performance will be investigated for pedestrian speed v=3 Km/h and slower vehicular speed v=60 Km/h. Fig. 9 illustrates the BER performance of the proposed system under both pedestrian and vehicular speeds. The FBI waiting period is 999.6 μs, i.e., the feedback is done every 120 data symbols. The lower bound of the performance is achieved under the pedestrian speed and as the velocity increases, the performance degrades. This is because the fading rate of change becomes slower as the velocity decreases. This will make the downlink channel parameters of the FBI message are considered as an accurate future predicted parameters for more number of the transmitted data symbols during the FBI waiting period and consequently, the performance improves.

In Fig. 10, the impact of the imbalance in the co-pol power intensities (CPF) on the BER performance is investigated. Zero channel cross-coupling was assumed in this figure. The best performance is achieved with equal co-pol average power intensities (CPF=$0dB$) and the performance degrades as the difference in the co-pol signal intensities increases. This is because as CPF increases, the total average SINR at the mobile terminal decreases due to the reduction in the received power at the HPol receiving antenna.

IV. Conclusion

In this paper, a novel closed loop polarized MIMO Pre-RAKE CTD system is proposed for the downlink in FDD mode. It can achieve a significant performance gain while preserving the simplicity of the receiver. This is in addition to reducing the spatial dimension and the power consumption of the mobile terminal. The proposed system outperforms the vertical MIMO Pre-RAKE CTD systems. This is due to the self-interference mitigation and achieving higher diversity degrees since the proposed system can enhance the cross-polarized signals. Also, the proposed system achieves a better performance than the advanced MIMO Pre/Post RAKE CTD systems which have complex receivers due to the post-RAKE circuit. The system performance using orthogonal carriers is better than using nonoverlapped carriers due to the increase in the processing gain. For slowly varying channels, as the FBI rate increases, the performance improves. Moreover, the system performs better in pedestrian environment than in vehicular environment. As the XPD increases, the performance of the proposed system improves whereas the performance improvement is inversely proportional with the envelope correlation. Finally, as the imbalance in the co-polarization power intensities increases, the BER performance degrades.

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