# Design and Performance of Adaptive Polarized MIMO MC-SS-CDMA System for Downlink Mobile Communications

Joseph V. M. Halim, Hesham El-Badawy, and Hadia M. El-Hennawy, Member, IEEE

*Abstract*— In this paper, an adaptive polarized Multiple-Input Multiple-Output (MIMO) Multicarrier Spread Spectrum Code Division Multiple Access (MC-SS-CDMA) system is designed for downlink mobile communications. The proposed system will be examined in Frequency Division Duplex (FDD) mode for both macro urban and suburban environments. For the same transmission bandwidth, a performance comparison between both nonoverlapped and orthogonal Frequency Division Multiplexing (FDM) schemes will be presented. Also, the proposed system will be compared with both the closed loop vertical MIMO MC-SS-CDMA system and the synchronous vertical STBC-MIMO MC-SS-CDMA system. As will be shown, the proposed system introduces a significant performance gain as well as reducing the spatial dimensions of the MIMO system and simplifying the receiver implementation. The effect of the polarization diversity characteristics on the BER performance will be discussed. Also, the impact of excluding the cross-polarization MC-SS-CDMA blocks in the base station will be investigated. In addition, the system performance will be evaluated under different Feedback Information (FBI) rates for slowly-varying channels. Finally, a performance comparison for vehicular and pedestrian environments will be presented.

*Keywords*— Closed loop technique, MC-SS-CDMA, Polarized MIMO systems, Transmit diversity.

## I. INTRODUCTION

RECENT researches draw an increasing interest to the polarized MIMO system for downlink wireless mobile communications. This is due to its capability of capacity enhancement as well as reducing the spatial dimensions of the MIMO system. Many investigations for the performance and configurations of the polarized MIMO channels have been made [1]-[4]. Results show that the capacity of polarized MIMO system outperforms that of the single-polarization MIMO system with constant Signal to Interference plus Noise (SINR) ratio.

Multicarrier CDMA techniques can be classified into two

Manuscript received April 22, 2008.

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main categories: Parallel transmission scheme of narrowband direct sequence waveforms in the frequency domain, using either nonoverlapped or orthogonal subcarriers. This type is called Multicarrier Direct Sequence Code Division Multiple Access (MC-DS-CDMA) [5]-[7]. The second type transmits each data symbol over $N$, nonoverlapped or orthogonal, narrowband subcarriers where $N$ is the spreading factor, also known as the Processing Gain (PG). This type is called Multicarrier Spread Spectrum Code Division Multiple Access (MC-SS-CDMA) [8]-[10].

In this paper, the proposed system applies the MC-SS-CDMA technique to the adaptive polarized MIMO technology for the downlink as an intuitive approach for accomplishing such technical advantages:

- Achieving a significant performance gain due to the combination between the spectral, the polarization and the spatial diversities.
- Capability of mitigating ISI and ICI since each subcarrier has a narrow bandwidth.
- Simple implementation and low complex receivers. The Discrete Fourier Transform (DFT) technique is used to reduce the transmitter and the receiver complexities. Also, the closed loop technique moves both the co-polarization (co-pol) and the cross-polarization (cross-pol) Maximal Ratio Combining (MRC) weighting units from the mobile to the base station (Node B in UMTS systems).
- High spectral efficiency, especially by using Orthogonal Frequency Division Multiplexing (OFDM) scheme.
- In the closed loop single-polarization MIMO MC-SS-CDMA systems, all transmitting and receiving antennas are vertical polarized dipoles. Self interference between the MC-SS-CDMA signals, transmitted from each antenna in the Node B to all receiving antennas, acts a challenge for these systems. In the proposed system, the self-interference is mitigated by transmitting the co-pol signals on orthogonal polarizations. In this paper, a performance comparison between the proposed system and the closed loop vertical MIMO MC-SS-CDMA system will be presented.
- Reducing the spatial dimensions for the MIMO system, where the costly spaced dipoles are replaced by dual 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 [11], [12].

- Ability to recover the polarization mismatch, which occurs when the polarizations of the transmitting and the receiving antennas are different.
- Capability of resolving the cross-pol signals, caused by the depolarization of the transmitted signals, at the receiver.

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 ($\rho_{env}$). The XPD is produced due to the depolarization of the transmitted signal by reflection, diffraction and scattering in the channel [13]. Also, it is defined as the ratio between the cross-polarized signal power to the co-polarized signal power. In urban and suburban environments, the XPD is normally between -1 and -10 dB, with an average of -6 dB [13], [14]. 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 [13]. 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 MC-SS-CDMA blocks in addition to the co-pol MC-SS-CDMA blocks in the Node B. The nature of electromagnetic wave propagation dictates that the polarization orthogonal to the obstacle is attenuated more than the polarization parallel to the obstacle [13], [15]. 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, $\rho_{env}$ 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 $\rho_{env}$ on the BER performance of the proposed system will be examined.

Recently, the Space-Time Block Coding (STBC) scheme has been introduced to the single-polarization MIMO MC-SS-CDMA systems [16]-[18]. Also, many equalization approaches were presented to maximize SINR at the diversity combiner. The basic equalization methods, which are Maximal Ratio Combining (MRC), Equal Gain Combining (EGC), Zero Forcing (ZF) and Minimum Mean Square Error (MMSE) equalization, have been compared in [16], [17]. However, a novel adaptive approach based on Minimum-BER (M-BER) concept was proposed in [18]. Results showed that the M-BER approach achieves the best performance. In this paper, the proposed system will be compared with the advanced synchronous vertical STBC-MIMO MC-SS-CDMA system, presented in [18].

This paper is organized as follows. In Section II, the

channel model is introduced. The proposed system is discussed in Section III. Section IV illustrates the simulation results. Finally, the conclusion is presented in Section V.

## II. CHANNEL MODEL

The channel is assumed to be a slowly-varying frequency-selective Rayleigh fading channel. The principal motivation for using MC-SS-CDMA is to allow a frequency-selective fading channel to appear as flat fading on each subcarrier, assuming that the number of subcarriers is sufficiently large [19]. For a particular downlink channel, the complex flat fading experienced by each subcarrier is described as:

$$h_{k,m_i,x,n}(t) = \beta_{k,m_i,x,n}\, e^{j\gamma_{k,m_i,x,n}}\; \delta(t) \tag{1}$$

where the subscript $i$ refers to the polarization type 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. $\beta_{k,m_i,x,n}$ represents the Rayleigh–distribution fade envelope (path gain) experienced by the $n^{th}$ subcarrier through $x^{th}$ polarization channel between the $m^{th}$ transmitting antenna of the $i^{th}$ polarization and the $k^{th}$ user's mobile terminal. It is treated as independent identically distributed (i.i.d.) Rayleigh random variable. Also, $\gamma_{k,m_i,x,n}$ is the i.i.d. uniformaly–distribution phase over [0, $2\pi$]. Finally, $\delta(\cdot)$ is the dirac delta function. The number of independent fadings in each particular channel is $L \cong N/Q$ where $N$ and $Q$ are the total number of subcarriers and the number of subcarriers that experience the same flat fading, respectively.

## III. PROPOSED SYSTEM

In the proposed system, the transmitter of the $k^{th}$ user in the Node B is shown in Fig. 1. After QPSK mapping and PN spreading stage, the signal is transmitted via $M$ dual polarized antennas. Orthogonality technique is utilized to mitigate the self-interference between both the co-pol and the cross-pol MC-SS-CDMA blocks. Each MC-SS-CDMA block consists of three stages; serial-to-parallel converter, weighting stage (Pre-equalization) and $N$-points IDFT modulation unit. The mobile terminal monitors the downlink channel all the time, using Training Signals (TS), transmitted from the Node B. The mobile feeds back the channel parameters to the Node B from time to time, depending on the rate of the feedback, via the FBI message. It should be noted that the FBI parameters are used in the Node B during the feedback-waiting period till the next update instant of the FBI message. After calculating the normalization factor $U_k$, the FBI message determination and calculations unit provides the MC-SS-CDMA blocks of each polarized antenna by their transmitting weights. Finally, the transmitted signal from each antenna is RF upconverted using the carrier frequency $\omega_o$.

The total normalization factor $U_k$, used to keep the total average transmitted power of the $k^{th}$ user constant, is
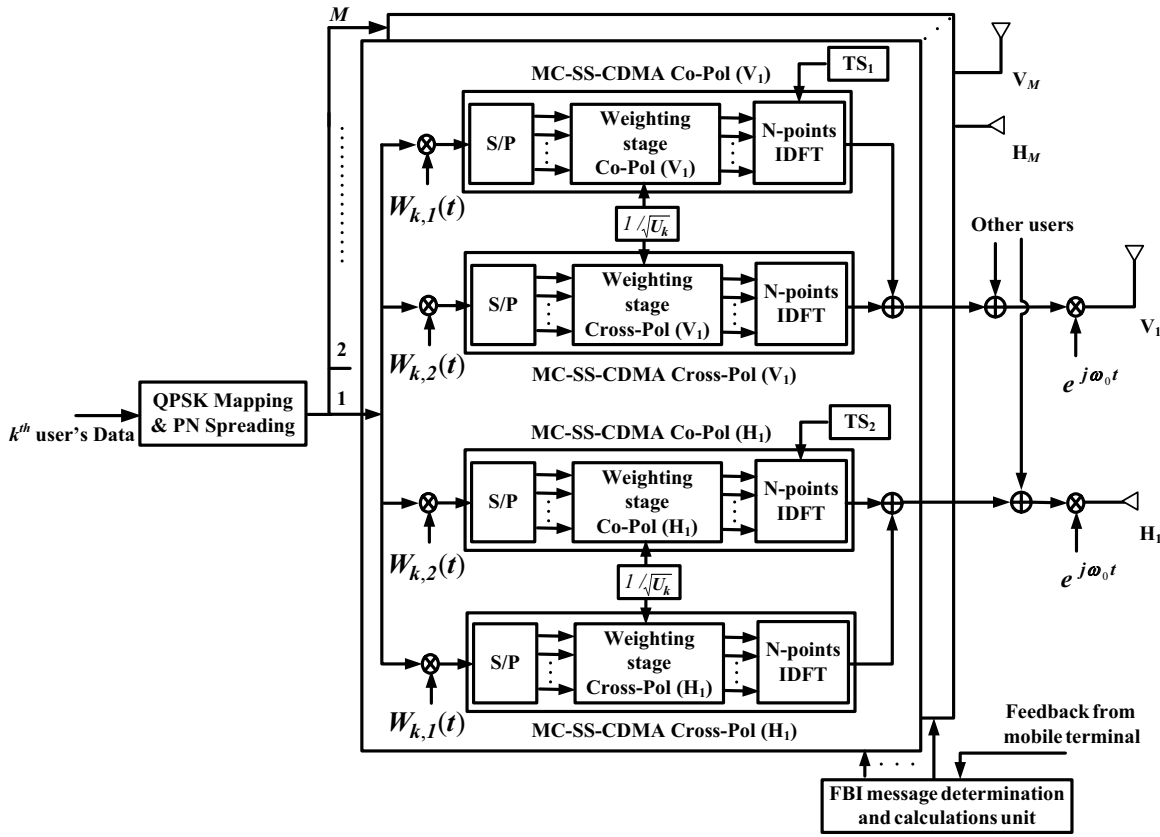
Fig. 1 Adaptive Polarized MIMO MC-SS-CDMA transmitter at the Node B

expressed as:

$$U_k = \sum_{i=1}^{2} U_{k,i} = \sum_{i=1}^{2} \left( \sum_{m_i=1}^{M} \sum_{x=1}^{X} \sum_{n=0}^{N-1} \beta_{k,m_i,x,n}^2 \right) \qquad (2)$$

where $U_{k,i}$ represents the normalization factor of the $k^{th}$ user, associated with the $i^{th}$ polarization. Also, $M$ is the number of transmitting antennas in each polarization. $X=2$ represents the co-pol and the cross-pol MC-SS-CDMA blocks for every transmitting antenna in each polarization. Hence, the transmitting weights in each MC-SS-CDMA block can be represented by:

$$B_{k,m_i,x,n} = \frac{\beta_{k,m_i,x,n} \, e^{-j\gamma_{k,m_i,x,n}}}{\sqrt{\sum_{i=1}^{2} \left( \sum_{m_i=1}^{M} \sum_{x=1}^{X} \sum_{n=0}^{N-1} \beta_{k,m_i,x,n}^2 \right)}} \qquad (3)$$

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

$$\sum_{i=1}^{2} \sum_{m_i=1}^{M} \sum_{x=1}^{X} \sum_{n=0}^{N-1} \left| B_{k,m_i,x,n} \right|^2 = 1 \qquad (4)$$

So, the total average transmitted power of the $k^{th}$ user is kept constant and independent on $N$, $X$ and $M$. Then, the RF $k^{th}$ user's signal, transmitted from the $m^{th}$ antenna in each polarization, can be represented as:

$$s_{k,m_i}(t) = \sum_{n=0}^{N-1} s_{k,m_i,n}(t) \qquad (5)$$

where $s_{k,m_i,n}(t)$ is the $n^{th}$ subcarrier component of the $k^{th}$ user's signal, transmitted from the $m_i^{th}$ transmitting antenna and it is expressed as:

$$s_{k,m_i,n}(t) = \sqrt{\frac{P_k}{U_k}} \sum_{x=1}^{X} \sum_{l=-\infty}^{+\infty} b_{k,l} c_{k,l,n} W_{k,y,n} \beta_{k,m_i,x,n} e^{j[2\pi(f_o+f_n)t-\gamma_{k,m_i,x,n}]} \qquad (6)$$

where $b_{k,l}$ is the $l^{th}$ QPSK data symbol of the $k^{th}$ user $\in \{(\pm 1 \pm j)/\sqrt{2}\}$. $c_k(t)$ is the aperiodic PN spreading sequence of the $k^{th}$ user. Consequently, $c_{k,l,n}$ denotes the $n^{th}$ chip belonging to the $l^{th}$ data symbol of the $k^{th}$ user's signal $\in [-1, 1]$. It should be noted that each user has a unique signature sequence $c_k(t)$ different from the other users. The subscript $y$ represents the periodic Walsh Hadamard code $W_{k,y}(t)$ such that

$y=1$ is used for the signals of the co-pol and the cross-pol MC-SS-CDMA blocks, associated with the VPol receiving antenna. However, $y=2$ is used for the signals of the co-pol and the cross-pol MC-SS-CDMA blocks, associated with the HPol receiving antenna. Consequently, $W_{k,y,n}$ is the $n^{th}$ chip of the periodic $y^{th}$ Walsh code for the $k^{th}$ user. Therefore, $Y=2$ refers to the number of Walsh codes, owned by each user in our system. Also, $P_k$ is the transmitted power and $f_o$ is the RF carrier frequency. Finally, $f_n$ is the baseband frequency of the subcarrier $n$ and it is given by [8]:

$$f_n = f_c + n \frac{F}{T_s} \quad , n = 0,1,2,........,N-1 \qquad (7)$$

where $f_c$ is baseband frequency of the first subcarrier, $T_s$ is the symbol duration and $F$ is the bandwidth expansion factor such that $F=1$ for OFDM scheme and $F=2$ for Nonoverlapped Frequency Division Multiplexing (NFDM) scheme. Table 1 illustrates the different combinations of the subscripts $i$ (Pol type), $x$ (Pol channel) and $y$ (Walsh code) in the system:

TABLE I
THE DIFFERENT USAGE COMBINATIONS OF THE SUBSCRIPTS $i$, $x$ AND $y$

| Pol type ($i$) | Pol channel ($x$) | Walsh code ($y$) |
|---|---|---|
| VPol ($i=1$) | co-pol ($x=1$) | Towards VPol Rx antenna ($y=1$), $W_{k,1}(t)$ |
| VPol ($i=1$) | cross-pol ($x=2$) | Towards HPol Rx antenna ($y=2$), $W_{k,2}(t)$ |
| HPol ($i=2$) | co-pol ($x=1$) | Towards HPol Rx antenna ($y=2$), $W_{k,2}(t)$ |
| HPol ($i=2$) | cross-pol ($x=2$) | Towards VPol Rx antenna ($y=1$), $W_{k,1}(t)$ |

A synchronous multicarrier 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:

$$r_{1,v}(t) = \text{Re}\left\{ \sum_{m_1=1}^{M} \left[ \sum_{n=0}^{N-1} \left( \sum_{k=1}^{K} s_{k,m_1,n}(t) \right) \otimes h_{1,m_1,1,n}(t) \right] \right\}$$
$$+ \text{Re}\left\{ \frac{1}{\sqrt{\zeta_{1,h}}} \sum_{m_2=1}^{M} \left[ \sum_{n=0}^{N-1} \left( \sum_{k=1}^{K} s_{k,m_2,n}(t) \right) \otimes h_{1,m_2,2,n}(t) \right] \right\} + n_v(t)$$
$$(8)$$

Similarly,

$$r_{1,h}(t) = \text{Re}\left\{ \sum_{m_2=1}^{M} \left[ \sum_{n=0}^{N-1} \left( \sum_{k=1}^{K} s_{k,m_2,n}(t) \right) \otimes h_{1,m_2,1,n}(t) \right] \right\}$$
$$+ \text{Re}\left\{ \frac{1}{\sqrt{\zeta_{1,v}}} \sum_{m_1=1}^{M} \left[ \sum_{n=0}^{N-1} \left( \sum_{k=1}^{K} s_{k,m_1,n}(t) \right) \otimes h_{1,m_1,2,n}(t) \right] \right\} + n_h(t)$$
$$(9)$$

where $\otimes$ is the convolution operation. Also, $\zeta_{1,v}$ 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. From Equations (1), (8) and (9), the received signals at the dual polarized antenna of the $1^{st}$ user's mobile can be represented as:

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

Similarly:

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

The receiver of the $1^{st}$ user's mobile has very simple implementation, as shown in Fig. 2. In each polarization, both co-pol and cross-pol received signals are RF downconverted using $\omega_o$ and demodulated by the N-points DFT. After parallel-to-serial process, $W_{1,1}(t)$ is used to despread the signals, associated with the VPol receiving antenna. However, the HPol receiving antenna uses $W_{1,2}(t)$ to despread its received signals. Hence, the signals of the receiving dual polarized antenna are combined together. As mentioned in equation (1), all subcarriers in any particular downlink channel have the same significant time delay $\delta(t)$. Therefore, only one matched filter is needed in the receiver to be tuned to this delay, as shown in Fig.2. Finally, the received signal is QPSK demapped before taking the decision.

## IV. SIMULATION RESULTS

Computer simulations were performed to evaluate the BER performance for the proposed adaptive polarized MIMO MC-SS-CDMA system in FDD mode. In the simulation, UMTS standard is considered where the RF carrier frequency is $f_o=2$ 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, which equals to the number of subcarriers of the MC-SS-CDMA block. Both the bit and the chip waveforms are rectangular $\in [-1,1]$. The coherence bandwidth of the channel in macro urban areas is $B_c \cong 245$ KHz (mean total RMS delay spread $\sigma_\tau=0.65$ $\mu s$) whereas it is $B_c \cong 936.7$ KHz ($\sigma_\tau=0.17$ $\mu s$) in macro suburban areas [20].Then, the narrow bandwidth of each subcarrier is
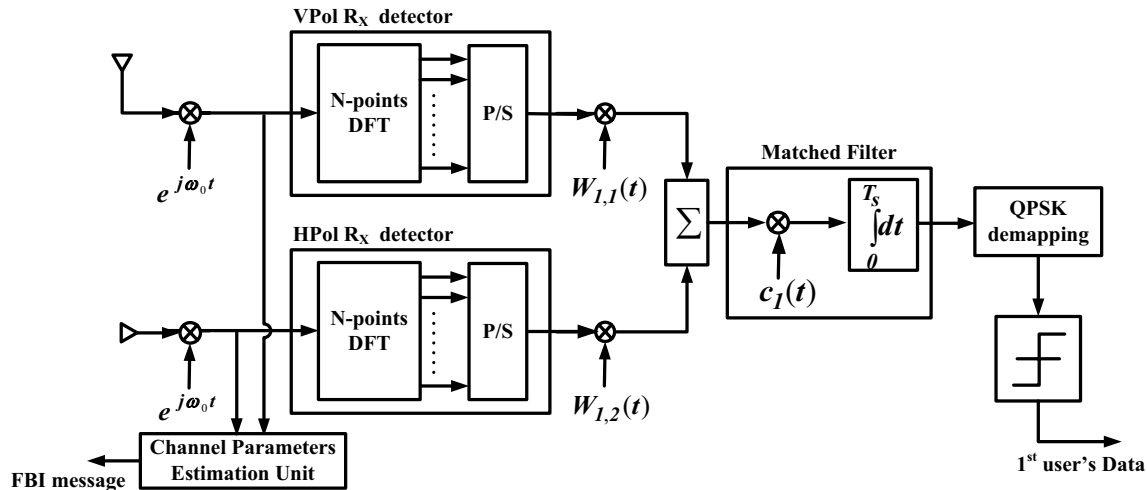
Fig. 2 Adaptive Polarized MIMO MC-SS-CDMA receiver of the 1st user's mobile

smaller than $B_c$ for both environments. Therefore, each subcarrier will experience flat fading channel whereas the whole wideband system experiences a frequency-selective fading channel. Also, if the frequency separation between the successive subcarriers equals or exceeds the coherence bandwidth of the channel ($\Delta f \geq B_c$), the subbands will experience independent fadings. However, if the successive subcarriers have a frequency separation less than the coherence bandwidth ($\Delta f < B_c$), the subbands will experience the same fading. 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. Consequently, the channel is considered as a slowly-varying Rayleigh fading channel. In the simulation, the proposed system employs only one dual polarized antenna in the mobile terminal. However, 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. Also, $P_r/(I_c+P_n)$ represents the ratio of the received power from the desired Node B to the undesired power from other Node Bs plus the thermal noise power at the mobile terminal. Finally, the simulation is run for $K$=10 users and in case of $F$=2 (NFDM scheme) and $F$=1 (OFDM scheme).

The first point is to compare the proposed system with the synchronous vertical STBC-MIMO MC-SS-CDMA system, presented in [18]. The performance comparison is performed using the same simulation parameters in paper [18], where the bit rate is $R_b$=1024 Kb/s, $B_d$=100 Hz, $N$=8, $K$=7 users and the channel flat fadings across different subcarriers are uncorrelated. Also, the proposed system is evaluated under XPD=0 dB, $\rho_{env}$=0% and using MRC pre-equalization scheme.

As shown in Fig. 3, the proposed 2x1 dual polarized MIMO MC-SS-CDMA system can achieve a significant performance gain over the 2x2 vertical STBC-MIMO MC-SS-CDMA system with different equalization approaches. At $10^{-3}$ BER, it has about 2.7 dB average gain over the M-BER 2x2 vertical STBC-MIMO MC-SS-CDMA scheme. This performance improvement is attributed to the capability of the proposed system to resolve the cross-pol signals in addition to the co-pol signals. Therefore, it can experience more independent fadings at the receiver and attain a higher diversity degree while reducing the spatial dimension in the mobile terminal.

In Fig. 4, a performance comparison between the proposed system and the closed loop vertical MIMO MC-SS-CDMA system is presented. The proposed system is evaluated under XPD=0 dB and $\rho_{env}$=0%. From the figure, many results can be concluded:

- The performance of 2x2 vertical MIMO MC-SS-CDMA system is similar to that in case of 2x1 vertical configuration. This is due to the self-interference between the MC-SS-CDMA blocks, transmitting their signals via the same transmitting antenna to all receiving antennas in the MIMO system.
- Using 1x1 dual polarized configuration, the proposed system outperforms the vertical 2x2 vertical MC-SS-CDMA system. This is in addition to reducing the spatial dimension in both the Node B and the mobile terminal. The superiority of the proposed system is attributed to two reasons: First, the accomplished polarization diversity gain, provided by the resolved co-pol and cross-pol paths. Second, the self-interference mitigation that gives the advantage of the proposed system in spite of it has the same diversity degree of the vertical system.
- By increasing the number of the dual polarized antennas in the Node B, the performance of the proposed system improves. This is due to the transmit diversity gain achieved in addition to the polarization diversity gain.
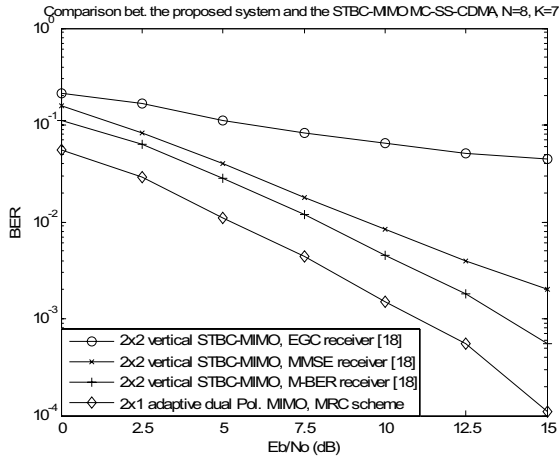
Fig. 3 A performance comparison between the proposed system and the synchronous vertical STBC-MIMO MC-SS-CDMA system



Fig. 4 A performance comparison between both Polarized and Vertical MIMO MC-SS-CDMA systems in Macro Urban environment

- In dense urban and suburban environments, the performance of the proposed system, without including the cross-pol MC-SS-CDMA blocks, is poor. This is because the XPD values in the dense areas approaches to 0 dB and consequently, the cross-pol signals cause a significant noise effect at the receiver. By adding the cross-pol MC-SS-CDMA blocks in the Node B, the proposed system can resolve the cross-pol signals in addition to the co-pol signals. Therefore, it mitigates the XPD noise effect and on the contrary, it exploits the cross-pol channels as resolved paths. Then, more independent fadings are experienced at the receiver and consequently, the performance improves.

In Fig. 5, the BER performance is investigated for both macro urban and suburban environments under different values of the bandwidth expansion factor ($F$). For the same transmission bandwidth, the OFDM scheme ($F=1$) outperforms the NFDM scheme ($F=2$). This is due to the increase in the spreading factor ($N$) since the number of subcarriers in the OFDM system is doubled. Also, the system performs better in urban areas than in suburban areas. This is because the coherence bandwidth of urban areas is smaller than that of suburban areas. Therefore, the number of subcarriers, which experience the same fading, in urban areas is smaller than that in case of suburban areas. Then, the MC-SS-CDMA system in urban areas employs more independent fadings and consequently, achieves a higher frequency diversity gain.

Fig. 6 evaluates the performance of the proposed system in macro urban environment under different FBI rates as well as various number of users. For slowly-varying channels, the BER performance improves as the FBI rate increases. This is because slower FBI rate results in larger feedback-waiting period. Therefore, the number of the transmitted symbols, which the downlink channel parameters of the FBI message will not be considered as an accurate future prediction about their fading profile, will increase. This causes degradation in the BER performance. As shown in the Figure, the lower
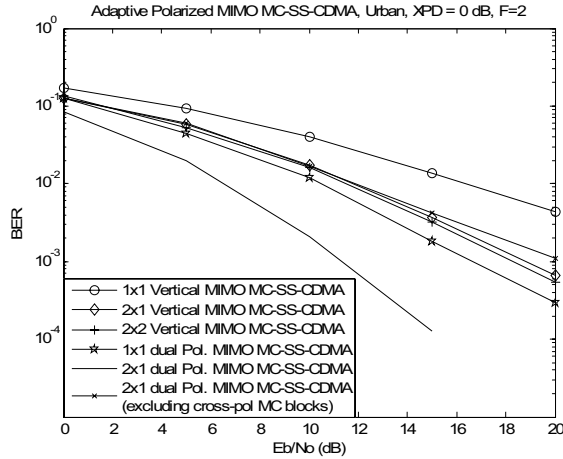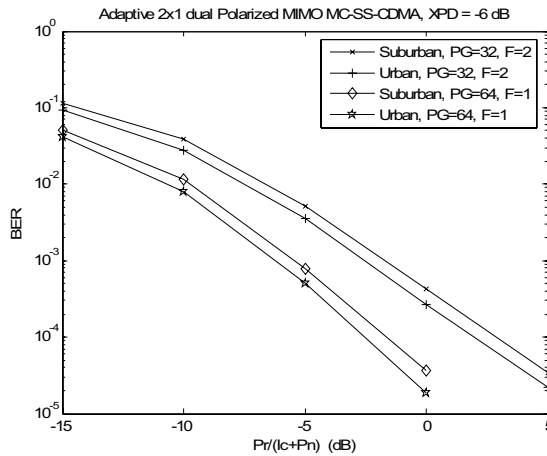


Fig. 5 The performance of the Adaptive Polarized MIMO MC-SS-CDMA system for both NFDM and OFDM in Macro Urban and Suburban environments

bound of the performance is achieved when the feedback is done every data symbol (FBI=120 KHz). For certain FBI rate, the performance degrades as the number of users ($K$) increases due to the Multiple Access Interference (MAI).

In Fig. 7, the proposed system is examined for both the vehicular and the pedestrian environments. 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.

Figs. 8 and 9 discuss the effect of the polarization diversity characteristics on the performance of the proposed system. Fig. 8 examines the performance under different values of XPD and $\rho_{env}$. However, the impact of the imbalance in the co-
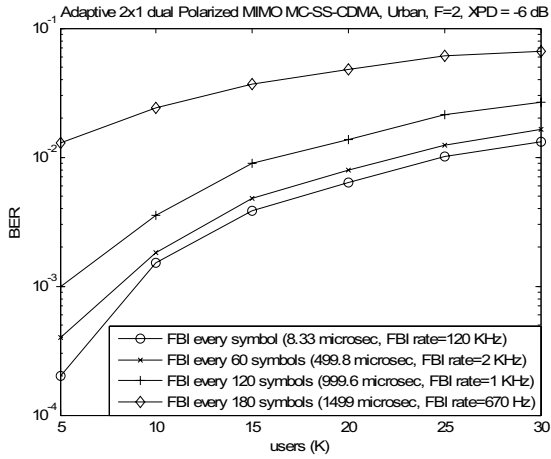
Fig. 6 The performance of the Adaptive Polarized MIMO MC-SS-CDMA system under different FBI rates, $E_b/N_o$=10 dB in Macro Urban environment
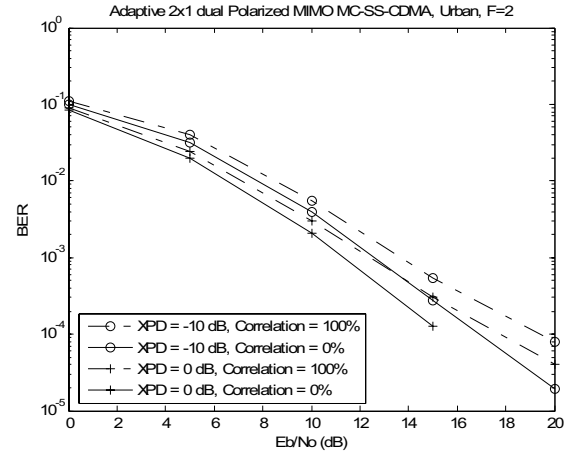


Fig. 8 The performance of the Adaptive Polarized MIMO MC-SS-CDMA system in Macro Urban environment under different values of XPD and $\rho_{env}$
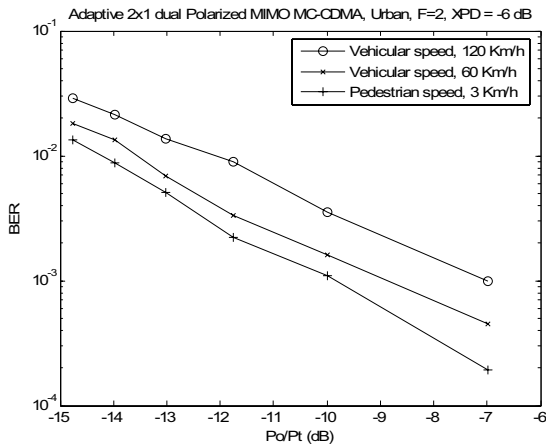


Fig. 7 The performance of the Adaptive Polarized MIMO MC-SS-CDMA system in Macro Urban environment for both vehicular and pedestrian speeds, $E_b/N_o$=10 dB
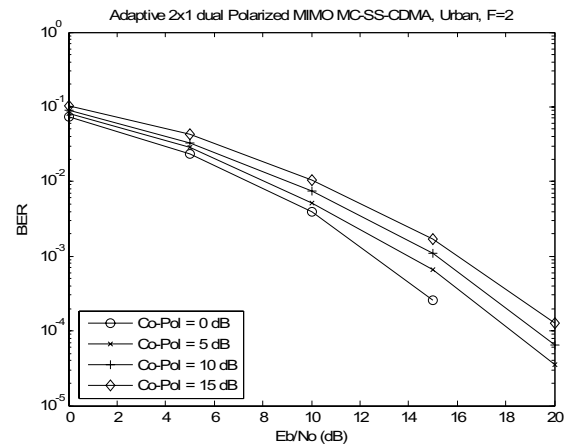


Fig. 9 The impact of the imbalance in the co-pol power intensities (CPF) on the BER performance of the Adaptive Polarized MIMO MC-SS-CDMA system in Macro Urban environment

pol power intensities (CPF) on the BER performance is investigated in Fig. 9, assuming zero channel cross-coupling. The performance improves as XPD increases and the lower bound of the performance is achieved when XPD=0 dB. This is attributed to the ability of the proposed system to resolve the cross-pol signals in addition to the co-pol signals for enhancing SINR. Also, the performance degrades as $\rho_{env}$ increases. This is because the envelope correlation between the fadings, experienced in the VPol and the HPol channels, becomes stronger with the increase in $\rho_{env}$. Finally, the performance improves as the difference in the average co-pol power intensities decreases and the best performance is achieved when they are balanced (CPF=0 dB). 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.

## V. CONCLUSION

In this paper, a novel adaptive polarized MIMO MC-SS-CDMA system is proposed in FDD mode for SINR enhancement. It is considered as a strong candidate approach for the downlink mobile communications due to the combination between the benefits of multicarrier CDMA, polarized MIMO and closed loop technologies. The proposed system can achieve a significant performance gain as well as simplifying the receiver implementation. Also, it outperforms both the closed loop vertical MIMO MC-SS-CDMA system and the synchronous vertical STBC-MIMO MC-SS-CDMA system. This is in addition to reducing the spatial dimensions of the MIMO system. If the space constraint allows two or more spatially separated dual polarized antennas in the Node B, the performance improves due to the transmit diversity gain. For the same transmission bandwidth, the system performance using OFDM scheme is better than using NFDM

scheme due to the increase in the processing gain. Also, the proposed system performs better in macro urban areas than in macro suburban areas. As the cross-polarization discrimination (XPD) increases, the BER performance improves. However, the performance improvement is inversely proportional with the envelope correlation ($\rho_{env}$) and the co-pol power factor (CPF). For slowly varying channels, the performance of the proposed system improves as the FBI rate increases. Finally, the system performs better in pedestrian environment than in vehicular environment.

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