

Design a Decoupled Receiver with One Dual - Polarized Antenna to Cancel CCI for GSM Network

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Abstract— The capacity of the popular GSM network is limited by co-channel interference (CCI) rather than noise. Nowadays, some solutions such as a receiver with multiple antennas (MIMO) or a receiver with single antenna interference cancellation (SAIC) have been applied to cancel the CCI as well as to improve the network capacity. According to this paper, a novel receiver system with only one dual-polarized antenna is introduced. The proposed system has some dominant characteristics than above systems. Actually, it has lower cost and volume than a MIMO system, whereas its performance is better than that of a SAIC system due to the additional polarization diversity.

Keywords— CCI, MIMO, SAIC, one-dual polarized antenna system, GSM

I. INTRODUCTION

In GSM network, the Cochannel Interference (CCI) has much more effect on the limitation of the network capacity rather than noise. Several techniques for CCI reduction have been introduced such as frequency hopping [1], multiple antenna approach [10], single antenna approach [1], [2], [3] polarized antenna approach [6], [7]-[9] for both narrowband and wideband systems. Among above mentioned solutions the multi-antenna receiver takes advantage of space and time diversity and space-time signal processing techniques so that its performance depends on uncorrelated property of the channels. The more antennas and the less correlation among those received signals, the higher benefit can be obtained. However, the multi-antenna receiver algorithm fails if the number of receive antennas does not exceed the number of interferers. Moreover, the volume of the receiver (Mobile Station) has to be large enough to exploiting many antennas with appropriate distance.

In recent years, a receiver with a Single Antenna (co-channel) Interference Cancellation (SAIC system) is a preferable solution, since the mobile stations are commonly (due to cost, volume, power consumption, and design aspects) equipped with only one antenna. Moreover, the downlink became bottleneck in the 2nd generation TDMA network due

to the introduction of multimedia services. In fact, the SAIC provides a good performance but it is typically rather complex.

The paper proposes a novel approach to combat CCI. In this proposal a decoupled receiver with one dual polarized antenna is analysed and designed. In fact, this receiver uses one antenna with two different polarized branches (i.e, one Vertical polarization branch and one Horizontal polarization branch). Due to two different polarized branches this receiver overcomes the limitations of cost and size as a drawback of a multi-antenna receiver. Furthermore, it also offers additional polarization diversity gain, i.e., it provides better performance than a SAIC system.

This paper focuses on design a receiver with one dual polarized antenna in conjunction with a decoupled linear filtering and a trellis-based equalization for synchronous GSM network. Additionally, only the training sequences of the desired user are assumed to be known to the receiver in advance.

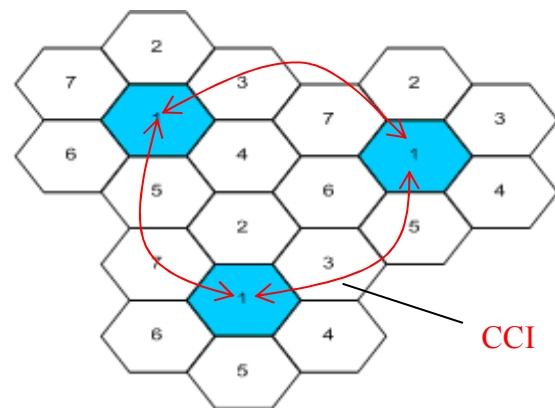


Figure 1. CCI appears due to frequency reused in GSM cellular network

II. THE MODEL OF A DECOUPLED RECEIVER EXPLOITING ONE DUAL-POLARIZED ANTENNA

A. Characteristic of Polarization Diversity

The nature of the wireless communication system creates polarization diversity due to the fact that the signal energy

from one polarization is generally coupled into other polarizations due to reflections and scattering caused by obstacles in the channel. Actually, the nature of the electromagnetic wave dictates that the polarization orthogonal to the obstacle surface is attenuated more than the polarization parallel to the surface [7], [8].

Normally, the envelope correlation (ρ_{env}) and the cross-polar-discrimination (XPD or χ) are two major parameters which are used to describe the characteristic of polarization diversity. The envelope correlation indicates the correlation among polarizations. In fact, correlation coefficients are lower in areas with a lot of scatters like trees or buildings..., as in urban area. The XPD indicates the power imbalance among polarizations. Ideally, the branches should have equal received powers to achieve maximum diversity gain. A large imbalance in the received power would render the whole diversity system worthless because the contribution of the weak channels will be negligible in a diversity combining scheme (e.g., equal gain or maximal ratio), whereas in a switched system the receiver will continually pick the strongest channel. These parameters (ρ_{env} , χ) strongly depend on the environment in the channel and vary from place to place [6].

Experimental results have shown that the envelope correlation between a Vertical Polarized branch (VPol) and a Horizontal Polarized branch (HPol) at a receiver is generally less than 0.2. Furthermore, the XPD in the urban and the suburban environment is among 1-10dB, with an average of 6dB. The XPD in the rural environment is among 10-18 dB, due to the lack of obstacles that couple the signal from the VPol into the HPol [6].

B. Receiver Model

Figure 2 shows the model of the proposed receiver. In this model one dual-polarized antenna is deployed. Two branches of the antenna are orthogonal. In order to suppress the CCI efficiently, a time-domain linear filter is introduced before a nonlinear detector in the receiver side, "Fig. 2". In this receiver the CCI cancellation and the ISI equalization in a slow frequency-selective Rayleigh fading are separated, so it is called a decoupled receiver. In fact, a linear filter is used to reduced the CCI, followed by a trellis-based equalizer for inter symbol interference (ISI) cancellation.

Moreover, the linear filter is used not only for interference reduction but also for channel shortening in order to degrade the complexity of the trellis-based equalizer. Therefore, this receive structure is called Decoupled linear filtering/ trellis-based equalization [3].

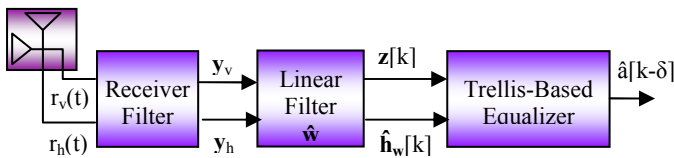


Figure 2. A decoupled receiver with one dual-polarized antenna

C. Channel Model

The channel model of the proposed receiver is described in Figure 3. This system deploys one dual – polarized antenna which includes one VPol and one HPol branch.

The total correlation matrix can be calculated by

$$\mathbf{R}_{tot} = \mathbf{R}_T \otimes \mathbf{R}_R \quad (1)$$

where $\mathbf{R}_T$ is the transmit correlation matrix,

$\mathbf{R}_R$ is the receive correlation matrix,

$\otimes$ is the Kronecker product

Here $\mathbf{R}_T = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$, because two antennas at transmitters (base stations) are independent and

$$\mathbf{R}_R = \begin{bmatrix} 1 & \sqrt{\frac{\rho_{env}}{\chi}} \\ \sqrt{\frac{\rho_{env}}{\chi}} & \frac{1}{\chi} \end{bmatrix},$$

where ρ_{env} is the envelope correlation indicating the correlation between the polarizations and χ is the cross-polar discrimination indicating the power imbalance between the polarizations.

We observe that the correlation coefficients (ρ) of the two polarization components can be estimated as the square root of the envelope correlation, i.e $\rho_{env} \cong \rho_{power} = \rho^2$ (for Rayleigh signals), whereas χ is defined as the ratio between the average power received on the VPol (vertical polarization branch) and the average power received on the HPol (horizontal polarization branch), given that the VPol is transmitted.

$$\chi = \frac{\bar{P}_{VPol,R_x}}{\bar{P}_{HPol,R_x}} \Big|_{VPol,T_x} \quad (2)$$

where $\bar{P}_{VPol,R_x}$ and $\bar{P}_{HPol,R_x}$ are the average power received on the VPol branch and the average power received on the HPol branch, respectively.

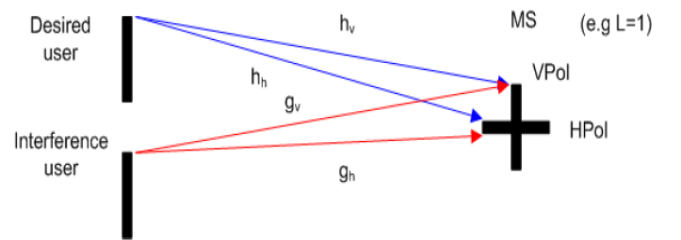


Figure 3. Channel model with one dual-polarized antenna

Therefore, the channel coefficients of the system will be calculated by:

$$\mathbf{h}' = \mathbf{R}_{tot} \cdot \mathbf{h} \quad (3)$$

where $\mathbf{h}$ is the channel coefficient matrix of the system with independent antennas at the receiver.

$$\mathbf{h}' = \mathbf{R}_{tot} \cdot \mathbf{h} = \begin{bmatrix} 1 & \sqrt{\frac{\rho_{env}}{\chi}} & 0 & 0 \\ \sqrt{\frac{\rho_{env}}{\chi}} & \frac{1}{\chi} & 0 & 0 \\ 0 & 0 & 1 & \sqrt{\frac{\rho_{env}}{\chi}} \\ 0 & 0 & \sqrt{\frac{\rho_{env}}{\chi}} & \frac{1}{\chi} \end{bmatrix} \cdot \begin{bmatrix} \mathbf{h}_1 \\ \mathbf{h}_2 \\ \mathbf{g}_1 \\ \mathbf{g}_2 \end{bmatrix}$$

$$\mathbf{h}' = \begin{bmatrix} \mathbf{h}_1 + \mathbf{h}_2 \cdot \sqrt{\frac{\rho_{env}}{\chi}} \\ \mathbf{h}_1 \cdot \sqrt{\frac{\rho_{env}}{\chi}} + \frac{1}{\chi} \cdot \mathbf{h}_2 \\ \mathbf{g}_1 + \mathbf{g}_2 \cdot \sqrt{\frac{\rho_{env}}{\chi}} \\ \mathbf{g}_1 \cdot \sqrt{\frac{\rho_{env}}{\chi}} + \frac{1}{\chi} \cdot \mathbf{g}_2 \end{bmatrix} = \begin{bmatrix} \mathbf{h}_v \\ \mathbf{h}_h \\ \mathbf{g}_v \\ \mathbf{g}_h \end{bmatrix} \quad (4)$$

$$\text{Set } \alpha = \sqrt{\frac{\rho_{env}}{\chi}}, \beta = 1/\chi.$$

From “(4)”, we have

$$\mathbf{h}_v = \mathbf{h}_1 + \mathbf{h}_2 \cdot \sqrt{\frac{\rho_{env}}{\chi}} = \mathbf{h}_1 + \alpha \mathbf{h}_2 \quad (5)$$

$$\mathbf{h}_h = \sqrt{\frac{\rho_{env}}{\chi}} \cdot \mathbf{h}_1 + \mathbf{h}_2 \cdot \frac{1}{\chi} = \alpha \mathbf{h}_1 + \beta \mathbf{h}_2 \quad (6)$$

$$\mathbf{g}_v = \mathbf{g}_1 + \sqrt{\frac{\rho_{env}}{\chi}} \cdot \mathbf{g}_2 = \mathbf{g}_1 + \alpha \mathbf{g}_2 \quad (7)$$

$$\mathbf{g}_h = \sqrt{\frac{\rho_{env}}{\chi}} \cdot \mathbf{g}_1 + \mathbf{g}_2 \cdot \frac{1}{\chi} = \alpha \mathbf{g}_1 + \beta \mathbf{g}_2 \quad (8)$$

Without loss of generality, it is assumed that only one dominant CCI is taken into account. In that case the received signals on vertical branch ($y_v[k]$) and on horizontal branch ($y_h[k]$) can be expressed by

$$y_v[k] = \sum_{l=0}^L h_{l,v}[k] a[k-l] + \sum_{l=0}^L g_{l,v}[k] b[k-l] + n_v[k]$$

$$= \sum_{l=0}^L (h_{l,1}[k] + \alpha h_{l,2}[k]) a[k-l] +$$

$$+ \sum_{l=0}^L (g_{l,1}[k] + \alpha g_{l,2}[k]) b[k-l] + n_v[k]$$

$$y_v[k] = y'_1[k] + \alpha y'_2[k] + n_v[k] \quad (9)$$

$$y_h[k] = \sum_{l=0}^L h_{l,h}[k] a[k-l] + \sum_{l=0}^L g_{l,h}[k] b[k-l] + n_h[k]$$

$$= \sum_{l=0}^L (\alpha h_{l,1}[k] + \beta h_{l,2}[k]) a[k-l] +$$

$$+ \sum_{l=0}^L (\alpha g_{l,1}[k] + \beta g_{l,2}[k]) b[k-l] + n_h[k]$$

$$y_h[k] = \alpha y'_1[k] + \beta y'_2[k] + n_h[k] \quad (10)$$

where $y'_1[k]$ and $y'_2[k]$ are received signals without noise on two independent antennas respectively; L is effective overall channel memory length of the discrete-time ISI channel model, k is the time index; $h_{l,v}[k]$ and $h_{l,h}[k]$ are the channel coefficients of the desired user, $g_{l,v}[k]$ and $g_{l,h}[k]$ are the channel coefficients of the interferer, $n_v[k]$ and $n_h[k]$ are k-sample of a Gaussian noise process; v and h stand for vertical branch and horizontal branch respectively; $a[k]$ and $b[k]$ are the k-th i.i.d (independent, identical distributed) data symbols of desired user and interferer respectively.

$$y'_1[k] = \sum_{l=0}^L h_{l,1}[k] a[k-l] + \sum_{l=0}^L g_{l,1}[k] b[k-l] \quad (11)$$

$$y'_2[k] = \sum_{l=0}^L h_{l,2}[k] a[k-l] + \sum_{l=0}^L g_{l,2}[k] b[k-l] \quad (12)$$

Assuming the noise powers are equal on both branches, $N_0^{(V)} = N_0^{(H)} = \frac{N_0}{2}$, where $N_0^{(V)}, N_0^{(H)}$ are noise power spectral density on VPol and HPol branches, respectively.

The power of received signal on the Hpol branch is χ time less than that on the VPol branch, i.e.,

$$E_H = \frac{1}{\chi} E_V \quad (13)$$

where, E_H and E_V are signal powers on VPol and HPol branches, respectively.

An ideal system is a two-branch receive diversity system in which two receiver's branches are uncorrelated and have the same average signal energy. This system can be viewed as a perfect spatial diversity system in which two vertical antennas are placed far enough from each other to ensure that the received signals are uncorrelated. It can also be viewed as a polarization diversity system with $\rho_{env} = 0$ and $\chi = 0$ dB. In that case, $\alpha = 0, \beta = 1$. This algorithm can also be applied to the case of more than one dominant interferer.

III. NUMERICAL RESULTS

Simulations are implemented for synchronous GSM network. GSM 05.05 typical urban (TU) with effective overall channel memory length of three ($L=3$) at a speed of 0 km (TU0) or 50 km (TU50) is used in the simulation since the urban environment is most likely be affected by co-channel interference. The case that the channel impulse responses (CIR) of the desired user are perfectly known to the equalizer

(perfect channel knowledge), and the case that CIR are estimated by means of training-based channel estimation (CE) are tested. We consider the case of one dominant interferer, channel estimation only available for the desired user and SNR = 25 dB. The noise variance $\sigma^2 = 0.03$ is chosen for the design of a linear filter. Maximum-likelihood sequence estimation (MLSE) [2] implemented with Viterbi algorithm (VA) is the optimal equalizer in the GSM system. In "Fig. 4" and Fig. 5, we show the bit error rate (BER) vs. the carrier-to-interference (C/I) ratio for the SAIC receiver, for the receiver with one dual-polarized antenna and for the receiver with 2 independent antennas. The average cross-polar-discrimination $\chi = 6$ dB and the envelope correlation $\rho_{\text{env}} = 0.2$ dB (the maximum values in experiment) are chosen for simulations shown in Figure 4 and Figure 5. By observing these figures we can easily realise that the proposed receiver with one dual-polarized antenna shows an improvement of 6dB and 2 dB (measured at $\text{BER}=10^{-3}$) over the SAIC receiver in case of TU0 and TU50 respectively, even though its performances are not as well as the performances of 2 independent antennas.

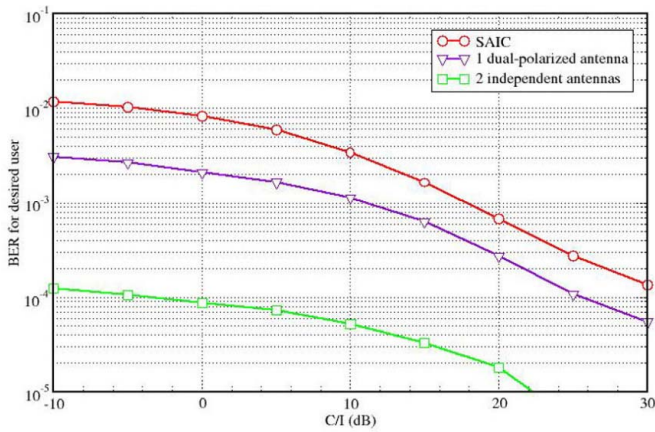


Figure 4. GSM, TU0 channel, perfect channel knowledge, SNR=25dB

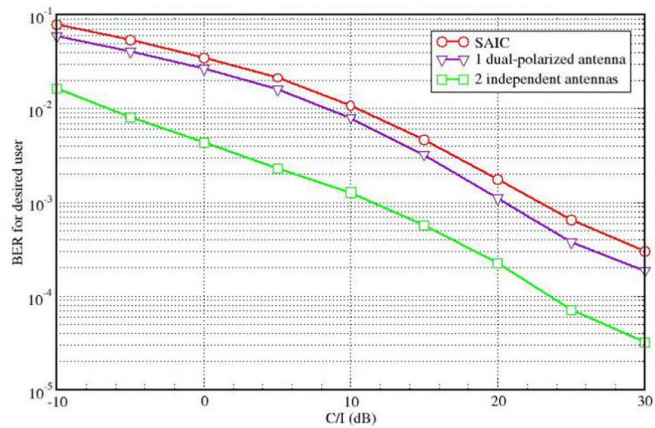


Figure 5. GSM, TU50 channel, correlative CE, SNR=25dB

Fig. 6 and Fig. 7 show that the performances of the proposed receiver become better and better in both cases of TU0 and TU50 when the value of χ is reduced gradually.

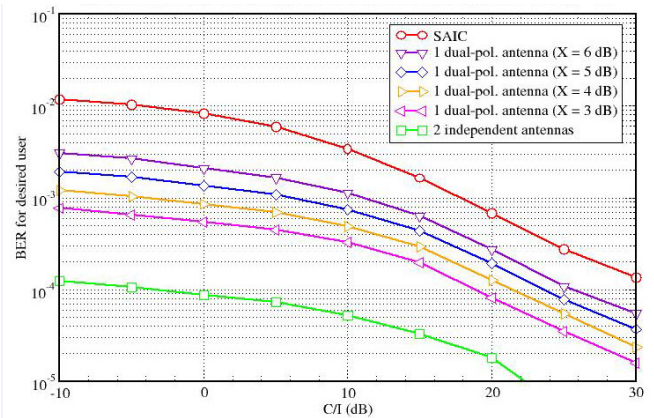


Figure 6. GSM, TU0 channel, perfect channel knowledge, SNR=25dB, $\rho = 0.2$, different values of X

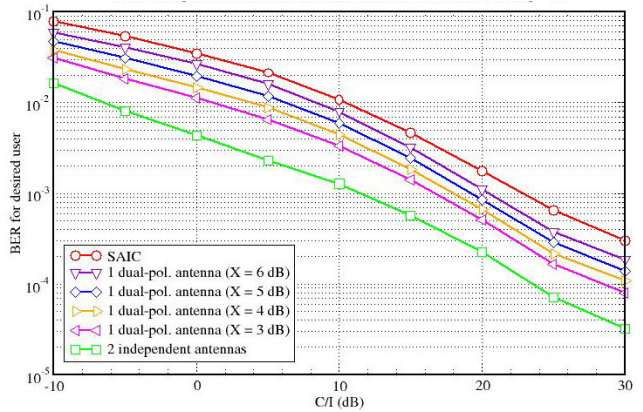


Figure 7. GSM, TU50 channel, correlative CE, SNR=25dB, $\rho = 0.2$, different values of X

IV. CONCLUSIONS

This paper introduces a proposed receiver with one dual-polarized antenna in order to reduce interference so that the performance of the received signal is improved. In this receiver, two orthogonal branches of the antenna provide orthogonal polarizations so that it has much better gain than the case of SAIC receiver. Moreover, the volume of the proposed receiver is reduced in comparison with the case of two independent antennas due to the fact that it uses only one antenna. A system simulation including the CCI cancellation scheme presented in this paper is an avenue for further research. In our future work, we intend to apply this scheme for the GSM network with more than one dominant interferer and for the EDGE network.

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