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EXPLOITING THE PILOT PATTERN ORTHOGONALITY OF OFDMA SIGNALS FOR THE ESTIMATION OF BASE STATIONS NUMBER OF ANTENNAS

Mohamed-Rabie Oularbi^{1,3}, Saeed Gazor², Abdeldjalil Aïssa-El-Bey^{1,3} and Sebastien Houcke^{1,3}

¹ Institut Télécom; Télécom Bretagne; UMR CNRS 6285 Lab-STICC
Technopôle Brest Iroise CS 83818 29238 Brest, France

² Department of Electrical and Computer Engineering, Queen's University, Kingston, Canada

³ Université européenne de Bretagne

ABSTRACT

In a recent work [1, 2], we proposed a GLR (Generalized Likelihood Ratio) test dedicated to the identification of OFDM systems. In the present paper, we show that the proposed technique can be extended for the estimation of the number of antennas used by a base station. This extension is made possible thanks to the orthogonality property that exhibits the pilot pattern associated to the different antennas. Thanks to a multi-hypothesis testing we show that the number of transmitting antennas is estimated using only one antenna at the receiver and without any knowledge of the pilot sequence.

1. INTRODUCTION

The combination Multiple Input Multiple Output (MIMO) and Orthogonal Frequency Division Multiplexing (OFDM) is widely used nowadays. Indeed, since it has been shown that this combo offers better performance than the Single Input Single Output (SISO)-OFDM configuration [3], standardization policies didn't hesitate to make use of it and one can see that some widespread OFDM based standards like : Long Term Evolution (LTE) [4], WiMAX Mobile [5], IEEE 802.11n [6], . . . , are proposing MIMO schemes. This new configuration of the base stations introduces a key challenge for cognitive opportunistic receivers : *the estimation of the number of transmit antenna of the base station.*

This knowledge can find many applications. First, in the secondary users (SUs) cohabiting with Primary Users (PUs) context, a multiple antennas PU may face heavier interference from SUs using any interference annealing technique. Therefore, based on this knowledge the SUs can use a higher power to communicate. Then, in the context of heterogeneous network, where many standards coexist, if a cognitive terminal¹ is trying to achieve the concept of "Always Best connected" [7], it must be able to choose the network with the best Quality of Service (QoS). The number of Base Station (BS) antennas is an important QoS metric and has significant impact on the link quality. Also, knowing the number of BS antennas

is a capital information when the opportunistic receiver is planning an association with the BS. This knowledge allows it to get a better understanding of the Signal to Noise Ratio and of the achievable bit-rate with the BS. An other key issue is to estimate the MIMO channel at the receiver, information needed for decoupling spatial streams and coherent data detection.

Some papers deal with the problem of estimating the number of transmit antennas in MIMO systems. In [8], authors proposed a detector based on objective information criteria (Akaike Information Criterion and Minimum Description Length estimators). In [9], the problem was simplified to a rank tracking issue. Then, the Schur complement was used to perform the rank estimation adaptively. For these two algorithms, the main limitation is that the both are based on the assumption that the cognitive receiver is doted of a number of antennas greater than the number of antennas at the transmitter, and thus are inefficient if this assumption is not fulfilled.

Recently, we proposed a technique based on the Pilot Induced Cyclo-stationarity (PIC) [10]. We showed that associating a Pilot induced Cyclo-stationarity with the orthogonality of the pilot pattern we can propose a detector that allows us to know how many antennas are used at the transmitter. The main drawback of this technique is that the Pilot induced Cyclo-stationarity is not always present on the signals, and if not available the proposed algorithm fails. In addition to this, it is very hard to imagine the modification of the way that the pilots are generated in order to meet the algorithm needs.

In this paper, we still make use of the pilot pattern orthogonality and associate it to a GLR test that we proposed in [1, 2]. This combination is exploited to set up a multiple-hypothesis composite enumeration problem tailored for full identification and Base Station number of antennas enumeration of an OFDM system. This algorithm fully identifies the transmitting system and provides estimates of channel gains and noise power. In addition to the fact that the algorithm performs without any knowledge of the pilot sequence, it allows to estimate it thanks to the proposed procedure in [11].

This paper is organized as follows. First, we propose the signal model in Section 2. Then, in Section 3 we remind the GLR test as proposed in [1, 2]. In Section 4, we

¹Here we define a cognitive terminal as a mobile doted of any form of cognition that helps him to sense and decide, but not specially a terminal able to detect white space.

show how the extension to the estimation of the number of antennas of a Base Station is possible. Simulations are assessed in Section 5. Finally, conclusions are drawn in Section 6.

2. SIGNAL MODEL

We assume that in a given frequency band, a transmitted OFDM signal consists of N sub-carriers, the discrete-time baseband equivalent received signal after cyclic prefix extraction and Fast Fourier Transform processing is given by

$$Y_{n,k} \triangleq H_k c_{n,k} + W_{n,k} \quad (1)$$

where n indicate the time index and k the frequency index, H_k is the channel frequency response on subcarrier k , in the derivation of our algorithm, we assume that the channel is time invariant. However, our simulation results indicate that the proposed algorithm performs well in slow time varying channels (see example in Section 5). The noise process $W_{n,k}$ is a Circularly Symmetrical Complex White Gaussian (CSCWG) noise, i.e., $W_{n,k} \sim \mathcal{CN}(0, \sigma^2)$ with zero mean and unknown variance of σ^2 . The modulating symbol $c_{n,k}$ is either a data symbol $d_{n,k}$ or a pilot symbol $p_{n,k}$ as follows

$$c_{n,k} = \begin{cases} p_{n,k} & \text{if } (n, k) \in \mathcal{P}, \\ d_{n,k} & \text{otherwise,} \end{cases} \quad (2)$$

where the pilot pattern \mathcal{P} represents the set of all pilot positions, i.e., $\mathcal{P} = \{(n, k) | n \text{ is the temporal location of a pilot and } k \text{ is the subcarrier index of a pilot}\}$. The pilot sequence $p_{n,k}$ is either a QPSK or BPSK signal in most existing systems, i.e., $p_{n,k} \in \{\pm 1, \pm \sqrt{-1}\}$. In a recent paper [2] we proposed a GLRT detector for OFDM systems that exploits only the pattern \mathcal{P} as input information and without any knowledge of the pilot sequence, in this paper we suggest to extend it for the estimation of the number of antennas.

3. REMINDER OF THE PROPOSED GLR TEST

First as proposed in [1], the GLR test was dedicated to OFDM system identification. This identification is made possible thanks to the fact that the pilot pattern are a discriminating signature, i.e.; one pilot pattern is associated exclusively to one and only one standard (Fig. 1).

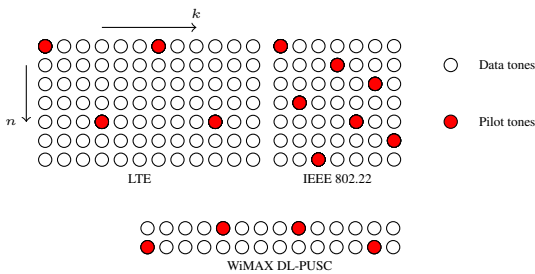


Fig. 1. Different configuration of pilot tones pattern.

The GLR test is constructed based on the following hypothesis :

$$\begin{cases} \mathcal{H}_0 & : \text{The system of interest is absent,} \\ \mathcal{H}_1 & : \text{The system using the pattern } \mathcal{P} \text{ is active.} \end{cases} \quad (3)$$

The hypothesis \mathcal{H}_0 represents the case in which these pilots are absent, i.e., the observed signal \mathbf{Y} is either a thermal noise (in the absence of any OFDM signal) or is produced by another system plus noise. These two case are not separated in this paper. The thermal noise \mathbf{Y} has a Gaussian distribution. We assume that any possible active system use the adaptive modulation and coding technique according to its SNR, i.e., it may transmit different constellations on different subcarriers (e.g., BPSK, QPSK, 16 QAM and 64 QAM for WiMAX and LTE). Thus the source symbols $c_{n,k}$ has a mixture probability distribution of all these modulations with unknown parameters. Making use of such a discrete mixture distribution for $c_{n,k}$ is impractical and requires dealing with many unknown parameters. In (8), $Y_{n,k}$ is a linear combination of independent random variables $c_{n,k}$ and noise. Thus by virtue of the central limit theorem, we may approximate the distribution of $Y_{n,k}$ for data samples with a normal distribution with zero mean and a variance σ_k^2 , i.e.,

$$f(\mathbf{Y} | \mathcal{H}_0, \sigma_k^2) = \prod_{k=0}^{N-1} \frac{1}{(\pi \sigma_k^2)^K} \exp\left(-\frac{1}{\sigma_k^2} \|\mathbf{Y}(k)\|^2\right), \quad (4)$$

where $\mathbf{Y}(k)$ is the vector observed on the k^{th} sub-carrier, $\|\cdot\|$ is the norm of its argument and K is the total number of observed OFDM symbols.

Under the hypothesis \mathcal{H}_1 , the OFDM system of interest is active and it is using the pilot pattern \mathcal{P} , taking into account the structure in \mathcal{H}_0 and the presence of \mathcal{P} , we can write :

$$f(\mathbf{Y}; \mathcal{H}_1, \sigma^2, \mathbf{C}, \mathbf{H}, \sigma_k^2) = \prod_k \left(\prod_{\nu \in \mathcal{P}_k} \frac{1}{\pi \sigma^2} e^{-\frac{1}{\sigma^2} |Y_\nu - H_k c_\nu|^2} \prod_{\nu \in \overline{\mathcal{P}}_k} \frac{1}{\pi \sigma_k^2} e^{-\frac{1}{\sigma_k^2} |Y_\nu|^2} \right) \quad (5)$$

where $\nu = (n, k)$ represents the time-frequency pair index. We denote $\mathcal{P}_k = \{(n, k) | \forall n\} \cap \mathcal{P}$ as the subset of pilot indices for a given sub-carrier k . It is obvious that $\{\mathcal{P}_k\}_{k=0}^{N-1}$ is a partition of \mathcal{P} . We denote $\overline{\mathcal{P}}_k = \{(n, k) | \forall n\} - \mathcal{P}$ as the subset of time-frequency pair indices which are not pilot for a given frequency index k . The cardinal number of a set \mathcal{A} is denoted by $|\mathcal{A}|$.

Thus, given equations (4) and (11), the problem of detecting an OFDM signal using a pilot pattern \mathcal{P} can be expressed by the following binary hypothesis test:

$$\begin{cases} f(\mathbf{Y} | \mathcal{H}_0, \sigma_k^2) & = \prod_{k=0}^{N-1} \frac{1}{(\pi \sigma_k^2)^K} \exp\left(-\frac{1}{\sigma_k^2} \|\mathbf{Y}(k)\|^2\right), \\ f(\mathbf{Y}; \mathcal{H}_1, \sigma^2, \mathbf{C}, \mathbf{H}, \sigma_k^2) & = \prod_k \left(\prod_{\nu \in \mathcal{P}_k} \frac{1}{\pi \sigma^2} e^{-\frac{1}{\sigma^2} |Y_\nu - H_k c_\nu|^2} \prod_{\nu \in \overline{\mathcal{P}}_k} \frac{1}{\pi \sigma_k^2} e^{-\frac{1}{\sigma_k^2} |Y_\nu|^2} \right). \end{cases}$$

To derive the GLR detector as proposed in [1], we first maximize (4) with respect to σ^2 and (11) with respect to

$(\sigma^2, \{\sigma_k^2\}_{k=0}^{N-1})$ to obtain the Maximum Likelihood (ML) estimates of σ^2, σ_k^2 respectively as follows

$$\mathcal{H}_0 : \quad \widehat{\sigma}_k^2 = \frac{1}{K} \|\mathbf{Y}(k)\|^2. \quad (6)$$

$$\mathcal{H}_1 : \quad \begin{cases} \widehat{\sigma}_k^2 &= \frac{1}{|\mathcal{P}_k|} \sum_{\nu \in \mathcal{P}_k} |Y_\nu|^2 \\ \mathbf{C} &: \text{ is estimated thanks to [11]} \\ \widehat{H}_k &= \frac{1}{|\mathcal{P}_k|} \sum_{\nu \in \mathcal{P}_k} \widehat{c}_\nu^H Y_\nu, \\ \widehat{\sigma}^2 &= \frac{1}{|\mathcal{P}|} \sum_k \sum_{\nu \in \mathcal{P}_k} |Y_\nu - H_k p_\nu|^2. \end{cases} \quad (7)$$

Thus, we define the following statistic test to decide if the pattern is present or not

$$\begin{aligned} \mathcal{T}(\mathbf{Y}, \mathcal{P}) &= K \sum_{k, \mathcal{P}_k \neq \emptyset} \log(\|\mathbf{Y}(k)\|^2) \\ &- |\mathcal{P}| \log \left(\sum_{k, \mathcal{P}_k \neq \emptyset} \left(\sum_{\nu \in \mathcal{P}_k} |Y_\nu|^2 - \frac{1}{|\mathcal{P}_k|} \left| \sum_{\nu \in \mathcal{P}_k} \widehat{c}_\nu^H Y_\nu \right|^2 \right) \right) \\ &- \sum_{k, \mathcal{P}_k \neq \emptyset} |\mathcal{P}_k| \log \left(\sum_{\nu \in \mathcal{P}_k} |Y_\nu|^2 \right) \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\geq}} \Lambda, \end{aligned}$$

where the detection threshold Λ_{det} can be obtained by Monte-carlo simulation, assuming that the pattern \mathcal{P} is absent (see Section 5 for more details).

4. EXTENSION TO THE NUMBER OF ANTENNAS ESTIMATION

In MIMO configuration, the pilots pattern are designed in such a manner to verify a certain orthogonality between the pattern associated to each antenna. Indeed, in Figure 2, one can check that for the LTE [4] a position dedicated to a pilot tone on an antenna is always forced to zero on all the others antenna, satisfying the fact that the received mixture signal on that position is a pure pilot tone. In the MIMO case (1) is expressed as

$$Y_{n,k} \triangleq \sum_{i=1}^M H_k^{(i)} c_{n,k}^{(i)} + W_{n,k}, \quad (8)$$

where M represents the number of transmit antennas and $H_k^{(i)}$ is the channel frequency response from the i^{th} antenna of the BS to the cognitive receiver. The modulating symbol $c_{n,k}^{(i)}$ in that case is thus given as

$$c_{n,k}^{(i)} = \begin{cases} p_{n,k} & \text{if } (n,k) \in \mathcal{P}^{(i)} \\ 0 & \text{if } (n,k) \in \mathcal{P}^{(j)}, \forall j \neq i \\ d_{n,k} & \text{otherwise} \end{cases} \quad (9)$$

where $\mathcal{P}^{(i)}$ is the pilot pattern associated to the i^{th} antenna.

We treat the numbering of transmitting antennas at the base station as a pilot pattern detection problem using the following multiple hypothesis test :

$$\begin{cases} \mathcal{H}_0 & : \text{ The system of interest is absent,} \\ \mathcal{H}_1 & : \text{ The pattern } \mathcal{P}^{(1)} \text{ is present,} \\ \mathcal{H}_2 & : \text{ The patterns } \mathcal{P}^{(1)} \text{ and } \mathcal{P}^{(2)} \text{ are present,} \\ \vdots & \vdots \\ \mathcal{H}_M & : \text{ The patterns } \mathcal{P}^{(1)}, \dots, \mathcal{P}^{(M)} \text{ are present.} \end{cases} \quad (10)$$

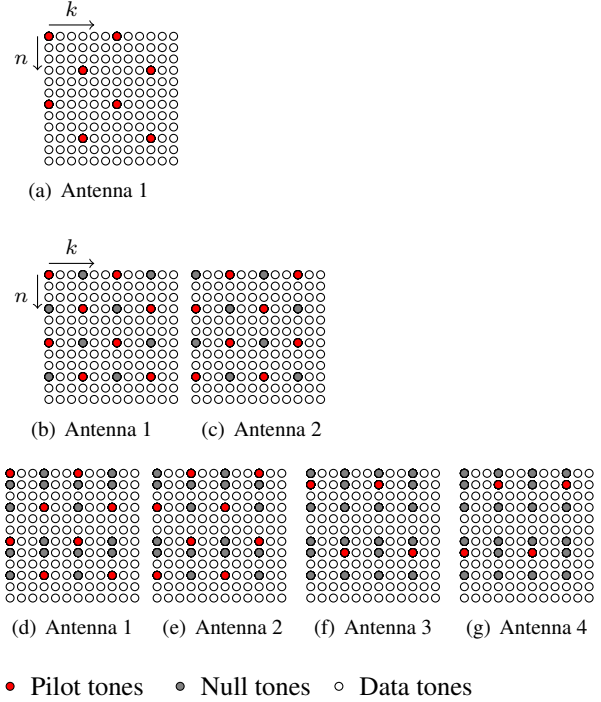


Fig. 2. Configuration of the pilot tones patterns in the LTE extended Cyclic Prefix mode [4]. Top : one antenna BS configuration, Middle : two antennas BS configuration, Bottom : four antennas configuration.

Indeed, we attempt to verify the presence of a given set of patterns simultaneously to determine the number of transmitting antennas, i.e, detecting the presence of M antennas is equivalent to detect the presence of M different pilot patterns.

Under \mathcal{H}_0 , the p.d.f of the observed signal remains the same. Under $\mathcal{H}_m, m = 1, \dots, M$, we can write:

$$f(\mathbf{Y}|\mathcal{H}_m, \sigma^2, \mathbf{C}, \{\mathbf{H}^{(i)}\}_{i=1}^m, \sigma_k^2) = \prod_{k=0}^{N-1} \left[\prod_{i=1}^m \left(\prod_{\nu \in \mathcal{P}_k^{(i)}} \frac{1}{\pi \sigma^2} e^{-\frac{1}{\sigma^2} \|Y_\nu - H_k^{(i)} p_\nu\|^2} \right) \prod_{\nu \in \mathcal{P}_k} \frac{1}{\pi \sigma_k^2} e^{-\frac{1}{\sigma_k^2} \|Y_\nu\|^2} \right], \quad (11)$$

The MLE of σ_k^2 under \mathcal{H}_0 and \mathcal{H}_1 remains the same as presented in the previous section. Under \mathcal{H}_m the pilot sequence \widehat{c}_ν is estimated using the algorithm in [11], and the channel response by

$$\widehat{H}_k^{(i)} = \frac{1}{|\mathcal{P}_k^{(i)}|} \sum_{\nu \in \mathcal{P}_k^{(i)}} \widehat{p}_\nu^H Y_\nu, \quad i = 1, \dots, m. \quad (12)$$

Finally the MLE of σ^2 is

$$\widehat{\sigma}^2 = \frac{1}{\sum_{i=1}^m |\mathcal{P}^{(i)}|} \sum_{i=1}^m \sum_{k, \mathcal{P}_k^{(i)} \neq \emptyset} \left[\sum_{\nu \in \mathcal{P}_k^{(i)}} |Y_\nu|^2 - \frac{1}{|\mathcal{P}_k^{(i)}|} \left| \sum_{\nu \in \mathcal{P}_k^{(i)}} \widehat{c}_\nu^H Y_\nu \right|^2 \right] \quad (13)$$

Substituting these ML estimates in (11) and (4) respectively and computing the difference of the logarithm of the result, we obtain the following log-likelihood GLR statis-

tic

$$\begin{aligned} \mathcal{T}_m(\mathbf{Y}, \mathcal{P}^{(1)}, \dots, \mathcal{P}^{(m)}) &= K \sum_{i=1}^m \sum_{k, \mathcal{P}_k^{(i)} \neq \emptyset} \log(\|\mathbf{Y}(k)\|^2) - \\ &\sum_{i=1}^m |\mathcal{P}^{(i)}| \log \left(\sum_{i=1}^m \sum_{k, \mathcal{P}_k^{(i)} \neq \emptyset} \left[\sum_{\nu \in \mathcal{P}_k^{(i)}} \|Y_\nu\|^2 - \frac{1}{|\mathcal{P}_k^{(i)}|} \left| \sum_{\nu \in \mathcal{P}_k^{(i)}} \hat{p}_\nu^H Y_\nu \right|^2 \right] \right) \\ &- \sum_{k, \forall i} \overline{|\mathcal{P}_k^{(i)}|} \log \left(\sum_{\nu \in \overline{\mathcal{P}_k^{(i)}}} |Y_\nu|^2 \right) \underset{\mathcal{H}_0}{\overset{\mathcal{H}_m}{\geq}} \Lambda_m, \end{aligned} \quad (14)$$

The detection threshold Λ_m is determined to satisfy a false alarm probability P_{fa} using $F_m(\Lambda_m) = 1 - P_{\text{fa}}$ where $F_m(\cdot)$ is the cumulative probability distribution of \mathcal{T}_m under \mathcal{H}_0 . Unfortunately, it is not easy to find the expression of $F_m(\cdot)$. To remedy this problem, we determine Λ_m by simulations (see Section 5 for more details).

The algorithm is a step by step algorithm : at each step we need to compute the test statistic associated to each antenna, using (14) and the associated threshold. For example, when treating the case of a four antennas base station, the algorithm starts by computing the test statistic associated to the first antenna $\mathcal{T}_1(\mathbf{Y}, \mathcal{P}^{(1)})$ and compares it to the threshold Λ_1 . If the test fails than we claims that the system is absent. Else, if $\mathcal{T}_1(\mathbf{Y}, \mathcal{P}^{(1)})$ is greater than Λ_1 , the algorithm will compute $\mathcal{T}_2(\mathbf{Y}, \mathcal{P}^{(1)}, \mathcal{P}^{(2)})$ associated to the second antenna and compare it to Λ_2 . If the test fails, than we decide that only one antenna is used by the BS, else if it is successful, than $\mathcal{T}_3(\mathbf{Y}, \mathcal{P}^{(1)}, \mathcal{P}^{(2)}, \mathcal{P}^{(3)})$ and $\mathcal{T}_3(\mathbf{Y}, \mathcal{P}^{(1)}, \mathcal{P}^{(2)}, \mathcal{P}^{(3)}, \mathcal{P}^{(4)})$ are computed and compared to Λ_3 and Λ_4 respectively, and a decision is done later according to if these two tests are positive or not (note that these two last tests are performed jointly, since the three antennas configuration does not exist). The whole procedure is summarized in Algorithm 1. The pro-

Algorithm 1 Summary of the proposed technique

- 1: Observe K OFDM symbols; Extract cyclic prefix; Perform N -points FFT;
 - 2: **for** $i = 1 : M$ **do**
 - 3: Read $\mathcal{P}^{(i)}$;
 - 4: Compute $\mathcal{T}_i(\mathbf{Y}, \mathcal{P}^{(1)}, \dots, \mathcal{P}^{(i)})$ as in (14);
 - 5: **if** $\mathcal{T}_i(\mathbf{Y}, \mathcal{P}^{(1)}, \dots, \mathcal{P}^{(i)}) > \Lambda_i$ **then**
 - 6: $i = i + 1$
 - 7: **else**
 - 8: $(i - 1)$ antennas are used;
 - 9: **break**;
 - 10: **end if**
 - 11: **end for**
-

posed algorithm performs an N -point Fast Fourier Transform (FFT) on K frames. Assuming that we have to detect the presence of up to m th antenna, we need to estimate $\sum_{i=1}^m |\mathcal{P}^{(i)}|$ PSK symbols by the algorithm proposed in [11]. Taking into account the complexity of each term in (6), the overall computational complexity is $KN(2 + \log_2 N) + \sum_{i=1}^m \sum_{k, \mathcal{P}_k^{(i)} \neq \emptyset} |\mathcal{P}_k^{(i)}| \log_2 |\mathcal{P}_k^{(i)}| +$

$\sum_{i=1}^m |\mathcal{P}^{(i)}|$, which is dominated by the term $KN(2 + \log_2 N)$.

Let $\mathcal{P}_{\varepsilon, \tau}^{(m)}$ denote the known pilot pattern shifted back in frequency ε and in time τ . We define the following decision statistic

$$\max_{(\varepsilon, \tau)} \{\mathcal{T}_m(\mathbf{Y}, \mathcal{P}_{\varepsilon, \tau}^{(m)})\} \underset{\mathcal{H}_0}{\overset{\mathcal{H}_1}{\geq}} \Lambda_m, \quad (15)$$

where \mathcal{T}_m is defined in (14). It is obvious that the $(\hat{\varepsilon}, \hat{\tau}) = \underset{\varepsilon, \tau}{\operatorname{argmax}} \{\mathcal{T}_m(\mathbf{Y}, \mathcal{P}_{\varepsilon, \tau}^{(m)})\}$ are maximum likelihood estimates of ε and τ . Note that this maximization is only required for the pilot pattern associated to the first antenna, since we can assume that as the antennas are co-localized the signals received on each antenna should suffer from the same time frequency shifts.

5. SIMULATION

For simulations, we consider LTE signals [4], with a total number of sub-carriers of $N = 512$, and the extended cyclic prefix signals of length $D = 128$. A group of 212 sub-carriers is forced to zero and dedicated to the guard intervals (right and left). The mapping of the pilot pattern is as illustrated in Figure 2, the number of observed OFDM symbols being $K = 48$. Note that to perform the identification the number of observed OFDM symbols should be at least equal to the length of the pattern. In the LTE case the longest patterns are the ones associated with the third and fourth antennas and are 12 symbols length. The propagation channel is simulated as a discrete time frequency selective channel assuming that the taps in time domain $\{h(l)\}_{l=0}^{L-1}$ are independent with zero-mean Gaussian distribution. We assume an exponential decay profile for the variance of $h(l)$, i.e., $E[|h(l)|^2] = Ge^{-l/\mu}$ for $l = 0, \dots, L - 1$ where G is chosen such that $\sum_{l=0}^{L-1} E[|h(l)|^2] = 1$. In the simulation $\mu = 0.25D$.

The decision threshold Λ_m is obtained by Monte Carlo simulation, assuming that the pilot pattern $\mathcal{P}^{(m)}$ is absent. In our simulations, the decision statistics for 10^4 independent trials in the absence of patterns are sorted in a descending order and the threshold is chosen as the $\%100 \times P_{\text{fa}}$ -percentile of the resulting data. For example for $P_{\text{fa}} = 0.02$, the threshold is chosen as the $0.02 \times 10^4 = 200$ th ordered data; i.e., such that $\%100 \times P_{\text{fa}}$ of the decision statistics are above the threshold. As an example in Figure 3, the obtained threshold is plotted versus the SNR, for various values of the P_{fa} . From this figure, we can conclude that the threshold has very small variation as a function of SNR; more specifically, the threshold varies only 3.3 % for 12 dB variation in SNR. Therefore, the proposed method requires only a coarse estimation of the SNR to achieve good performance.

Figure 4 shows the probability of correct detection of the number of antennas versus the SNR, for the cases of one, two and four antennas base station, where the threshold is determined using the true SNR or using a coarsely

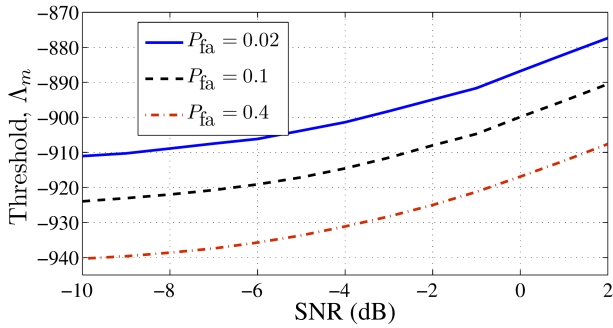


Fig. 3. Threshold values versus the SNR for the detection of the first antenna for various values of the probabilities of false alarm, LTE signals, $N = 512$, $D = 128$, $K = 48$, $M = 1$.

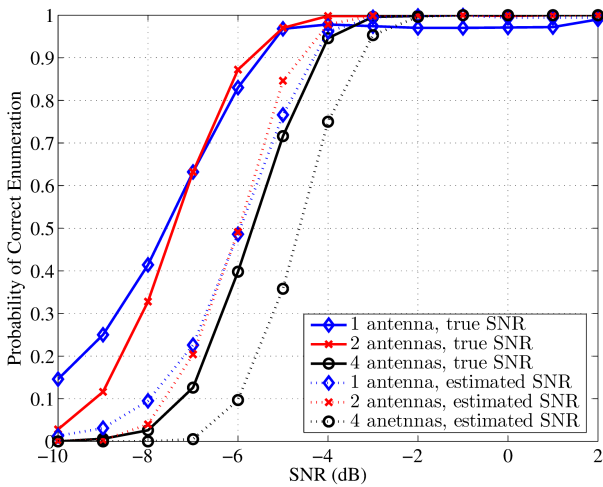


Fig. 4. Probability of correct estimation of the number of used antennas by the base station. LTE signals, $N = 512$, $D = 128$, $K = 48$, $M = 1, 2$ and 4 , $P_{fa} = 0.02$.

estimated SNR. We can observe that the proposed technique achieves satisfactory performance starting from -4 dB. For the case of four antennas the performance decreases since the power density of each pilot tone is reduced by 3 dB. The SNRs in Figure 4 are estimated by estimating the noise power from the guard interval subcarriers (as no information is transmitted through them), and estimating the signal power from the data subcarriers. We see that using the estimated SNR the proposed techniques has some insignificant performance loss compared to the case of using the true SNR.

Figure 5 illustrates the impact of a time-varying frequency-selective channel simulated using Jakes' model for maximum Doppler frequencies $f_d = 0, 100$ and 300 Hz and a nominal false alarm rate of $P_{fa} = 0.02$. We see that the proposed algorithm is robust to Doppler spread for $f_d = 100$ Hz, and the loss in performance is less than 2 dB in SNR. However for fast varying environments such as $f_d = 300$ Hz the performance is seriously degraded. We must note that such large Doppler frequency is not expected as $f_d = 300$ Hz represents a relative velocity of 162

km/h, at 2 GHz.

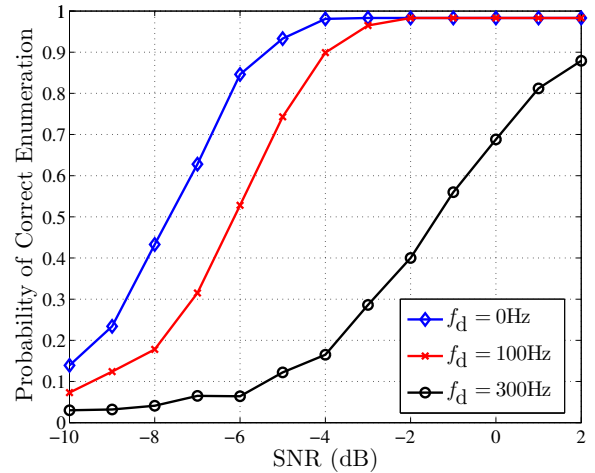


Fig. 5. Effect of Doppler spread on probability of correct estimation of a one antenna BS. LTE signals, $N = 512$, $D = 128$, $K = 48$, $P_{fa} = 0.02$.

Finally, in figure 6, we compare the proposed method in this paper to the one based on the PIC detector that we proposed in [10]. One can see that the new proposed algorithm outperforms the old one and that we achieve high probabilities of correct enumeration with the GLRT at lower SNRs than with the PIC. When the PIC operates without any knowledge of the SNR it requires the existence of a correlation between the pilots. On the other hand, when the GLRT operates even when this correlation is absent, it requires a coarse estimation of the SNR.

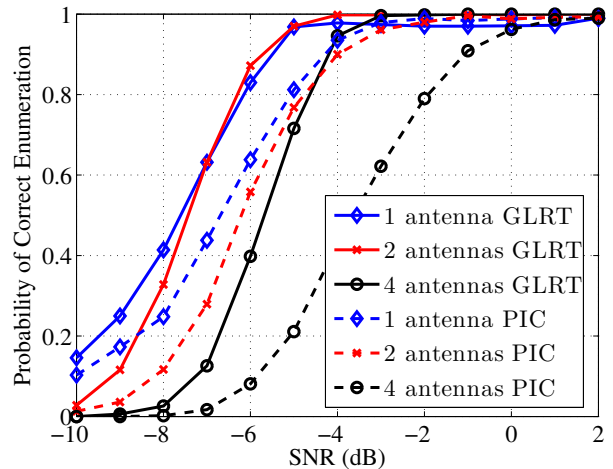


Fig. 6. PIC based technique versus the proposed method. LTE signals, $N = 512$, $D = 128$, $K = 48$, $P_{fa} = 0.02$.

6. CONCLUSION

In this paper, we proposed a new algorithm for the enumeration of the transmit antennas at the base station of an

OFDM system. This algorithm allows to perform such a task employing only one antenna at reception regardless of the number of transmit antenna. Simulations results show that the performance is satisfactory for cognitive radio applications and outperforms the one proposed in [10].

7. REFERENCES

- [1] M-R. Oularbi, S. Gazor, S. Houcke, and A. Aïssa-El-Bey, "GLR Test for OFDM System Identification Using Pilot Tones Pattern," *EURASIP Journal on Wireless Communications and Networking*, vol. 2013, no. 72, March 2013.
- [2] M-R. Oularbi, S. Gazor, S. Houcke, and A. Aïssa-El-Bey, "OFDM system identification using pilot tone signature," in *The 7th International Workshop on Systems, Signal Processing and their Applications (WOSSPA)*, May 2011.
- [3] H. Bolcskei, D. Gesbert, and A.J. Paulraj, "On the capacity of OFDM-based spatial multiplexing systems," *IEEE Transactions on Communications*, vol. 50, no. 2, pp. 225–234, 2002.
- [4] 3GPP support office, *3GPP TS 36.211 V8.6.0 (2009-03), Technical Specification, 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA); Physical Channels and Modulation (Release 8)*, 2009.
- [5] IEEE Std 802.16, *Part 16: air interface for broadband wireless access systems, Amendment 2 : Physical and Medium Access Control layers for Combined Fixed and Mobile Operation in License Bands and Corrigendum 1*, 2005.
- [6] *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications : Enhancements for Higher Throughput*, 2006.
- [7] E. Gustafsson and A. Jonsson, "Always best connected," *Wireless Communications, IEEE*, vol. 10, no. 1, pp. 49–55, feb. 2003.
- [8] O. Somekh, O. Simeone, Y. Bar-Ness, and W. Su, "Detecting the Number of Transmit Antennas with Unauthorized or Cognitive Receivers in MIMO Systems," in *MILCOM*, oct 2007.
- [9] M. Shi, Y. Bar-Ness, and W. Su, "Adaptive estimation of the number of transmit antennas," in *MILCOM*, oct 2007.
- [10] M-R. Oularbi, A. Aïssa-El-Bey, and S. Houcke, "Introducing Pilot Cyclostationarity for LTE Base Station Number of Antennas Estimation," in *IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC)*, September 2012, pp. 2202–2207.
- [11] S. Gazor, M. Derakhtian, and A.A. Tadaion, "Computationally Efficient Maximum Likelihood Sequence Estimation and Activity Detection for M - PSK Signals in Unknown Flat Fading Channels," *Signal Processing Letters, IEEE*, vol. 17, no. 10, pp. 871–874, oct. 2010.