APPLICATION OF SOURCE SEPARATION ALGORITHMS FOR MOBILE COMMUNICATION ENVIRONMENT

Mei Feng and Karl-Dirk Kammeyer

University of Bremen, FB-1, Department of Telecommunications

P.O. Box 33 04 40, D-28334 Bremen, Germany, Fax: +(49)-421/218-3341, e-mail: feng@comm.uni-bremen.de

ABSTRACT

In the most source separation algorithms the classical narrow band data model is used, where only memoryless transmission channels are considered. In the mobile communication environment we have to deal with multipath transmission channels due to the reflections of wavefronts. In order to apply existing source separation algorithms for mobile communication signals, certain modifications of the classical narrow band data model have to be done. In this paper a modification of the data model using OFDM–technique is presented. Using the OFDM–technique the assumption of narrow band signals (needed for the most source separation algorithms) is met automatically. A source separation algorithm named SSARS (Source Separation Algorithm with Reference System) will be considered in this paper in cases of transmission through random multipath test channels as well as mobile communication channels. Simulation results will show the efficiency of the new OFDM data model in comparison to the existing MIMO data model.

1. INTRODUCTION

In recent years array processing techniques have been proposed for applications in communication systems [1] [2]. In mobile communication systems, it has been shown that spatial reuse of allocated frequency slots by employing an antenna array increases the system capacity substantially. A new multiple access technique named SDMA (Spatial Division Multiple Access) has arisen based on this property. Using the SDMA technique, the individual users which are sending from different positions, could be identified at the receiver even if all the source signals are transmitted within the same time slot and using the same frequency slot. The central component of the SDMA technique is actually a source separation algorithm.

In this paper only blind source separation methods will be considered. The "blind" qualification refers to the coefficients of the transmission channels: no *a priori* information is assumed to be available. Diverse algorithms on this topic already exist, which are based either on the second order statistics [3] [4] [5] or on the fourth order statistics [6] [7] [8] or on both of them [9] [10] [11]. The most of them take use of the classical narrow band data model, where only memoryless transmission channels are considered. Using such a data model, mobile communication signals can not be separated due to the existence of delayed multiple paths of the sources.

In order to apply existing source separation algorithms for mobile communication signals, certain modifications of the classical narrow band data model have to be done. One modification from the literature is the MIMO (Multiple Inputs Multiple Outputs) data model, which is used i.e. in [12] [13]. In the MIMO data model each delayed version of the sources is considered as a new source signal, so that the number of sources, which are to be separated, increases substantially. That implies that the number of sensors needed for the separation increases substantially too.

In this paper a new modification of the data model using OFDM–technique will be presented. Using the OFDM–technique the assumption of narrow band signals (needed for the most source separation algorithms) is met automatically. Therefore, no increase in the number of sensors is needed even in the presence of delayed multiple paths. In order to show the efficiency of the new technique a source separation algorithm named SSARS (Source Separation Algorithm with Reference System) [11] will be considered in cases of transmission through random multipath test channels as well as mobile communication channels.

This paper is organized as follows. In section 2 the classical narrow band data model will be described. In section 3 the MIMO data model will be described briefly. In section 4 the new modification using OFDM–technique will be presented. In section 5 a summary about the SSARS source separation algorithm follows and in section 6 simulation results with random multipath test channels as well as with mobile communication channels will be presented. The conclusion follows in section 7.

2. CLASSICAL NARROW BAND DATA MODEL

Consider the mixture model illustrated in figure 1 where s_i are narrow band independent sources, r_i are additive Gaus-

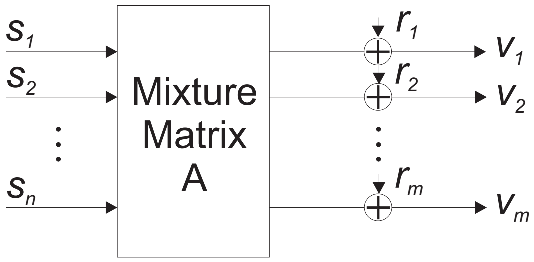

Figure 1: Mixture model in the array processing

sian noise components and v_i are the observations. We assume that the number of sensors m is larger than or equal the number of sources n. Using matrix notation, the relationship between the observations and the sources at distinct times t can be expressed through the following linear noisy model:

$$\mathbf{v}(t) = \mathbf{A}\mathbf{s}(t) + \mathbf{r}(t) \tag{1}$$

where

- $\mathbf{s}(t)$ is the $n \times 1$ vector of complex–valued sources, which are modeled as zero–mean, non–Gaussian and statistically independent random processes. $\mathbf{s}(t) = [s_1(t), s_2(t), \ldots, s_n(t)]^T$.
- $\mathbf{v}(t)$ is the $m \times 1$ vector of observations with $\mathbf{v}(t) = [v_1(t), v_2(t), \ldots, v_m(t)]^T$.
- $\mathbf{A}$ is the $m \times n$ complex–valued mixture matrix with linearly independent columns.
- $\mathbf{r}(t)$ is the $m \times 1$ Gaussian noise vector whose components are independent and identically distributed.

From the above data model (1) we can see that each channel between emitter and sensor consists of only one complex factor (element of $\mathbf{A}$). That means, that in the data model (1) all source signals are assumed to be narrow band signals and the transmission channels are assumed to be memoryless.

In the mobile communication environment delayed versions of the sources have to be considered, what implies that the assumption of narrow band signals is not met any more. Thus, the data model described in (1) can not be used in such cases.

3. MIMO DATA MODEL

One modification of the classical narrow band data model for mobile communication signals is the well–known MIMO data model, which has been used i.e. in [12] [13].

In the MIMO data model each delayed version of the sources is considered as a new source signal, so that the assumption of narrow band signals needed in the classical data model in (1) is met again. The data model in (1) can then be rewritten as:

$$\mathbf{v}(t) = \mathbf{A}_{\text{mimo}} \cdot \mathbf{s}_{\text{mimo}}(t) + \mathbf{r}(t) \tag{2}$$

with

$$\mathbf{s}_{\text{mimo}}(t) = [\mathbf{s}_1(t), \mathbf{s}_2(t), \ldots, \mathbf{s}_n(t)]^T , \tag{3}$$

where

$$\mathbf{s}_i(t) = [s_i(t), s_i(t-1), \ldots, s_i(t-\tau_i)]^T \tag{4}$$

with $i = 1, \cdots, n$. τ_i is the delay spread associated with source i. The mixture matrix $\mathbf{A}_{\text{mimo}}$ has here a dimension of $m \times ((\tau_1 + 1) + (\tau_2 + 1) + \ldots + (\tau_n + 1))$, and consists of impulse responses of the transmission channels:

$$\mathbf{A}_{\text{mimo}} = [\, \mathbf{H}_1, \ \mathbf{H}_2, \ldots, \ \mathbf{H}_n], \tag{5}$$

where

$$\mathbf{H}_i = \begin{bmatrix} \mathbf{h}_1^{(i)} \\ \mathbf{h}_2^{(i)} \\ \vdots \\ \mathbf{h}_m^{(i)} \end{bmatrix}, \qquad i = 1, \cdots, n \tag{6}$$

$\mathbf{h}_j^{(i)}$'s in (6) are $1 \times (\tau_i + 1)$ row vectors with Elements that are the impulse response of the transmission channel between the i–th emitter and the j–th sensor.

Using the MIMO data model, it is now possible to apply existing source separation algorithms, which are based on the classical narrow band data model, for mobile communication signals. However, from equations (2)–(4) we can see that altogether $\sum_{i=1}^{n}(\tau_i + 1)$ signals have to be separated if there are n independent sources. Then, more than $\sum_{i=1}^{n}(\tau_i + 1)$ sensors are needed at the receiver, what could be a very expensive deal.

4. MODIFICATION USING OFDM–TECHNIQUE

From communication theories we know, that using the OFDM (Orthogonal Frequency Division Mutiplexing)–technique transmission channels are divided into several sub–channels, where frequency response of each sub–channel can be assumed to be constant [14] [15]. Then, for the output signal of each sub–channel at the receiver the assumption of narrow band signals needed for the classical narrow band data model is met automatically.

With this knowledge a new modification of the classical data model using OFDM–technique is presented.

In figure 2 the transmitter of our new data model is shown. Each source signal s_i is transmitted through an OFDM–transmitter, which divides each transmission channel into M sub–channels. The transmitted signal of the i–th source $\tilde{s}_i$ is the sum of all components s_i^k of this source, which

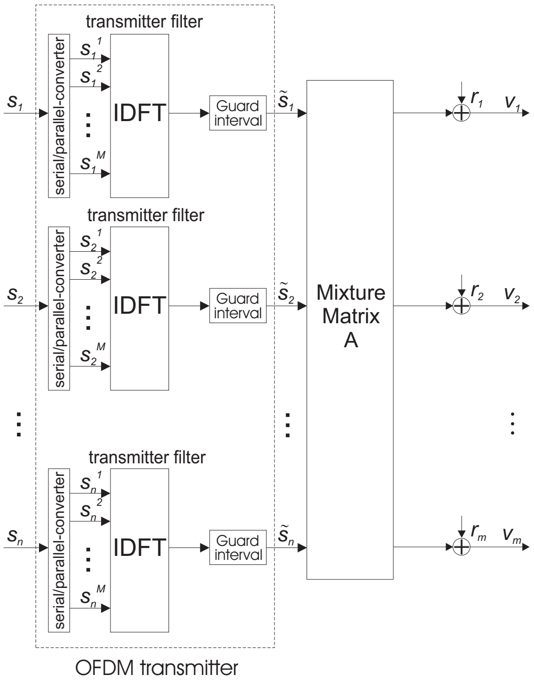

Figure 2: Modification of the classical narrow band data model using OFDM–technique: transmitter

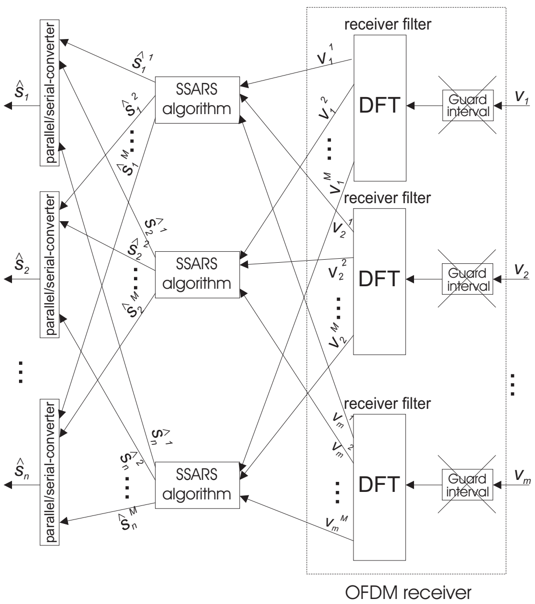

Figure 3: Modification of the classical narrow band data model using OFDM–technique: receiver

have been shifted into different subbands with an IDFT–processor

$$\tilde{s}_i(t) = \sum_{k=1}^{M} s_i^k e^{j2\pi f_k t} \quad (7)$$

$$= \mathrm{IDFT}_M\{s_i^k\}, \quad (8)$$

where f_k is the frequency of the k–th sub–channel. The guard–interval in figure 2 is a special technique in OFDM for the suppression of the ICI (Inter-Channel-Interference), that is caused by delay spread of the sources.

After reception with the sensor array the guard–interval has to be removed (see figure 3). Then, subband signals of each observation v_i can be recovered with a DFT–processor.

Within each sub–channel the corresponding subband signals at the OFDM–receiver can be described with the classical narrow band data model, since the assumption of narrow band signals is met there:

$$\mathbf{v}^k(t) = \mathbf{A}_k\, \mathbf{s}^k(t) + \mathbf{r}^k(t), \qquad k = 1, \cdots, M \quad (9)$$

where

$$\mathbf{v}^k(t) = [v_1^k, v_2^k, \cdots, v_m^k]^T,$$
$$\mathbf{s}^k(t) = [s_1^k, s_2^k, \cdots, s_n^k]^T,$$

and

$$\mathbf{r}^k(t) = [r_1^k, r_2^k, \cdots, r_m^k]^T.$$

Apply the SSARS algorithm to all sub–channels. After a parallel/serial converter similarly to the serial/parallel converter at the transmitter, the source signals can be estimated up to a complex scale factor.

5. SSARS SOURCE SEPARATION ALGORITHM

In this paper the recently presented source separation algorithm SSARS [11] is used to show the efficiency of the new data model with OFDM–modification.

In the SSARS algorithm both second– and higher–order statistics of the received data are applied. Unlike conventional methods an added reference system of the separation matrix is inserted here in order to get high separation quality with low computational cost. The separation matrix will be updated iteratively by the reference system (see figure 4).

In figure 4, $\mathbf{W}$ is an $n \times m$ whitening matrix such that $\mathbf{Wv}$ is spatially white. $\mathbf{B}$ is a unitary $n \times n$ separation matrix and $\mathbf{R}$ is the added reference system.

In the following a brief summary of the SSARS algorithm is presented:

1. Find the whitening matrix $\mathbf{W}$ through eigen value decomposition of the sample correlation matrix $\mathbf{R_{vv}}$. More details can be found in [9].

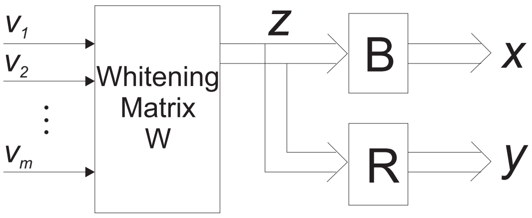

Figure 4: Separation Model

2. Set the reference system $\mathbf{R} = \mathbf{I}$ and the iteration number $it_{no} = 1$.
3. Compute $\mathbf{B}_{it_{no}}$ using the joint diagonalisation algorithm from Cardoso [9]:
$$\sum_{i=1}^{n} |diag(\mathbf{B}_{it_{no}} \cdot \text{cum}(\mathbf{z}^* y_i^* y_i \mathbf{z}) \cdot \mathbf{B}_{it_{no}}^H)|^2 = \text{max}.$$
4. Set $\mathbf{R} = \mathbf{B}_{it_{no}}$ and compute
$$\mathbf{y}^{it_{no}} = \mathbf{Rz}.$$
5. Repeat step 3 with $\mathbf{y}^{it_{no}} \Longrightarrow \mathbf{B}_{it_{no}+1}$.
6. Set $it_{no} = it_{no} + 1$ and repeat step 4 and 5 several times.

In the most cases good estimation results can be received after only two iteration steps (Simulations can be found in [11]). Therefore, the number of iteration steps is set to be two for all simulations in this paper.

6. SIMULATION RESULTS

In the following simulation experiments linear uniform arrays with m sensors are used (m is variable in each experiment). Three independent narrow band source signals are impinging on the array. The first one is QPSK modulated, the second one is BPSK modulated and the third one is QPSK modulated. In each simulation only 100 data samples are used for estimates of the correlation matrix and the cumulant matrix, so that the assumption of time invariance of transmission channels can be met, even in real communication cases. Simulation results of all experiments in this section are averaged versions of 10000 Monte–Carlo–Runs.

Experiment 1: In this experiment the MIMO data model and the new OFDM data model will be compared, where random channels with delay spread of two are used. A profile of the channel responses is shown in figure 5.

Since there are three independent sources considered and each source has two echo paths, then using MIMO data model there are altogether nine signals that have to be separated. From array processing theory we know that more than nine sensors are then needed for separations.

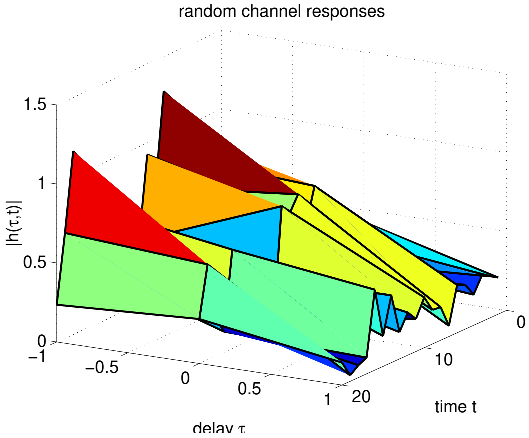

Figure 5: A profile of random channel responses with delay spread equal two

In our simulations with the MIMO data model, once 10 sensors and once 12 sensors are used. In figure 6 the bit error rates (BER) of the first QPSK source with the SSARS–algorithm using MIMO data model are plotted in terms of E_s/N_0 for both cases, where E_s is the symbol energy and N_0 is the (one sided) power spectral density of the complex white channel noise.

As a comparison the bit error rates of the first QPSK source using the OFDM data model with only 4 sensors are plotted in figure 6 too.

From the comparison in figure 6 we can see that using the OFDM data model better separation quality can be obtained even with significantly smaller number of sensors.

Experiment 2: In this experiment mobile communication channels generated using the models of COST–207 for bad urban environment are considered, which have a doppler frequency of 200Hz and a carrier frequency of 900MHz. The maximum delay spread of this channel type is five. A profile of the channel responses is shown in figure 7.

From *Experiment 1* we have seen that the OFDM data model is much more efficient than the MIMO data model. Therefore, in this experiment only the OFDM data model is applied to the bad urban channel. Bit error rates of all three Sources using the SSARS algorithm are plotted in figure 8.

From figure 8 we can see that using the SSARS algorithm, error floors of the QPSK signals are observed in figure 8. However, the separation results can still be seen as good, since BER≈ 10^{-3} for 100 data samples means that only one per mille bits of the 100 data samples is wrong.

Generally we can say that using the OFDM data model all existing source separation algorithms, that are based on the classical narrow band data model, can be applied to mobile communication signals without any increase of the number of sensors.

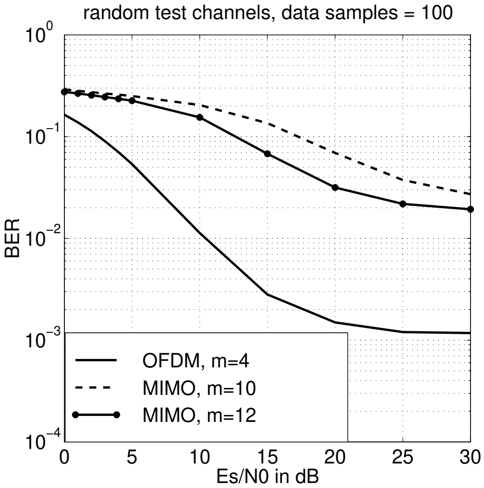

Figure 6: Simulated bit error rates of the first QPSK source using both MIMO data model and OFDM data model for different number of sensors

Figure 7: A profile of bad urban channel responses with $f_{\text{doppler}} = 200\text{Hz}$ and $f_{\text{carrier}} = 900\text{MHz}$. The delay spread is equal five.

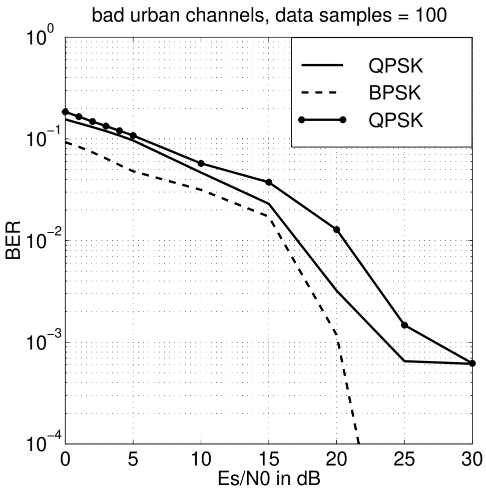

Figure 8: Simulated bit error rates of the SSARS algrithm using OFDM data model during transmission through bad urban channels

7. CONCLUSION

In this paper a new modification of the classical data model using OFDM–technique is presented (called OFDM data model). Using this modification the assumption of narrow band signals, that is needed for the most source separation algorithms, is met automatically. Therefore, unlike the well–known MIMO data model all existing source separation algorithms that are based on the classical narrow band data model can be applied to multipath transmission channels without any increase of the number of sensors. Thus, we can say that a direct bridge between the array processing theory and the practice of mobile communications is build with the new OFDM data model.

In this paper, the efficiency of the OFDM data model is shown with a blind source separation algorithm named SSARS. Random transmission channels as well as mobile communication channels have been considered. From the comparison between the MIMO data model and the new OFDM data model we have shown that better separation quality can be obtained using the OFDM data model even with significantly smaller number of sensors.

8. REFERENCES

[1] J.H. Winters. Optimum Combining in Digital Mobile Radio with Co-Channel Interference. *IEEE Trans. Veh. Technol.*, VT-33:144–155, August 1984.

[2] D.J. Edwards S.C. Swales, M.A. Beach and J.P. McGeehan. The Performance Enhancement of Multibeam Adaptive Base Station Antennas for Cellular

Land Mobile Radio Systems. *IEEE Trans. Veh. Technol.*, VT-39:56–67, Februar 1990.

[3] C. Jutten C.G. Puntonet, A. Prieto and et al. Separation of Sources: A Geometry-Based Procedure for Reconstruction of n-Valued Signals. *EURASIP Signal Processing*, 46:267–284, 1995.

[4] Stefaan Van Gerven and Dirk Van Compernolle. Signal Separation by Symmetric Adaptive Deccorelation: Stability, Convergence, and Uniqueness. *IEEE Trans. on Signal Processing*, 43(7):1602–1612, July 1995.

[5] U. Lindgren and A. van der Veen. Source Separation Based on Second Order Statistics – an Algebraic Approach. In *Proc. of IEEE workshop on SSAP, Corfou, Greece*, pages 324–327, 1996.

[6] P. Common. Independent Component Analysis. In *Proc. International Signal Processing Workshop on Higher Order Statistics*, pages 111–120, Chamrousse, France, June 1991.

[7] J. F. Cardoso. Iterative Techniques for Blind Source Separation using Only Fourth-Order Cumulants. *EURASIP Signal Processing: Theory and Applications*, VI:739–742, 1992.

[8] A. Mansour and C. Jutten. A Direct Solution for Blind Separation of Sources. *IEEE Trans. on Acoustics, Speech and Signal Processing*, 44:746–748, 1996.

[9] J.F. Cardoso and A. Souloumiac. Blind Beamforming for Non Gaussian Signals. In *IEE Proceedings-F*, volume 140(6), pages 362–370, December 1993.

[10] S. Bose J.F. Cardoso and B. Friedlander. On Optimal Source Separation Based on Second and Fourth Order Cumulants. In *Proc. of IEEE workshop on SSAP, Corfou, Greece*, pages 198–201, 1996.

[11] M. Feng and K. D. Kammeyer. Blind Source Separation for Communication Signals Using Antenna Arrays. accepted by ICUPC'98, Oct. 1998.

[12] C.B. Papadias and A.J. Paulraj. A Constant Modulus Algorithm for Multiuser Signal Separation in Presence of Delay Spread Using Antenna Arrays. *IEEE Signal Processing Letters*, 4:178–181, 1997.

[13] J. Xavier and V. Barroso. A Geometry Matching Approach for Blind Inversion of MIMO Binary Channels. submitted to Wireless Personal Communications, Special Issue on SDMA, 1998.

[14] J. G. Proakis. *Digital Communications*. McGraw-Hill, third edition, 1995.

[15] K. D. Kammeyer. *Nachrichten übertragung*. Teubner, Stuttgart, second edition, 1996.