Transmitters Separation for Single Frequency Networks

Gilles Burel, Pierre Magniez

To cite this version:

Gilles Burel, Pierre Magniez. Transmitters Separation for Single Frequency Networks. IEEE Workshop on Signal Processing Advances in Wireless Communications, May 1999, Annapolis, United States. pp.341-344, 10.1109/SPAWC.1999.783088. hal-03223343

HAL Id: hal-03223343

https://hal.univ-brest.fr/hal-03223343v1

Submitted on 17 Mar 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Copyright

IEEE-SPAWC, May 1999, Annapolis, Maryland, USA
(IEEE Workshop on Signal Processing Advances in Wireless Communications, pp. 341-344, Annapolis, Maryland, May 9-12, 1999)

Transmitters Separation for Single Frequency Networks

Gilles BUREL and Pierre MAGNIEZ[1]
L.E.S.T., Université de Bretagne Occidentale
6, Avenue Le Gorgeu - BP809 - 29285 BREST cedex - France
tel : (33).2.98.01.62.46 fax : (33).2.98.01.63.95
email : Gilles.Burel@univ-brest.fr

Abstract

In a Single Frequency Network (SFN), the signals coming from nearby transmitters are mixed. Since the interfering signals can be seen as (very) long term echoes, an effective method to combat echoes, such as OFDM, is a natural candidate for SFN. However, although OFDM is a very efficient method, the very long delays that characterise SFN echoes require extremely long packets in OFDM transmissions and high stability of the subcarriers frequencies.

An alternative approach based on array processing is proposed. The signals received by the sensors are filtered and downconverted. Then, source separation is performed using transmitters localisation and multiplication by the pseudo-inverse of the estimated mixture matrix. Symbol Timing and Carrier Recovery is then performed on each separated component.

Furthermore, in order to increase the SNR, these components can be globally synchronised (using a correlator) and summed. Experimental results are finally presented and show good performances of the approach in a realistic configuration.

Keywords

Array Signal Processing in wireless systems, Signal Separation, Single Frequency Networks

1

1. Single Frequency Networks

A Single Frequency Network (SFN) is a digital broadcasting network in which all the transmitters dedicated to the retransmission of a given program use the same frequency band. Hence, SFN requires much less spectrum than classical broadcasting networks because there is no frequency allocation. In a classical network, about 9 frequency bands per program are allocated: close transmitters use different bands in order to avoid interferences.

SFN is believed to progressively replace classical broadcasting networks in the future. However, the price to pay for the gain on spectrum allocation is the need of more sophisticated signal processing. Since the transmitters use the same frequency band, the receiver gets a mixture of signals coming from the closest transmitters. Signal processing must be performed in order to separate the components of this mixture.

2. The traditional approach to SFN :OFDM

Most research works about SFN consider the use of OFDM (Orthogonal Frequency Division Multiplexing). OFDM is indeed a good candidate for SFN, because of its power in reducing the effect of echoes. The basic idea is to consider the interfering signals as long term echoes.

More precisely, the received signal in a given frequency band is a mixture of delayed versions of the basic signal. The delays correspond to the various propagation times (which are proportional to the distances between the transmitters and the receiver). As shown on figure 1, the signal received from transmitter 2 can be seen as a delayed version of the signal coming from transmitter 1. The delay is proportional to D_2-D_1 (plus delays due to the paths from the original transmitter to transmitters 1 and 2). A typical propagation delay, for a difference of distances equal to 30 km, is 100µs. With a symbol frequency equal to 10MHz, this corresponds to a delay of 1000 symbols.

Hence, from the receiver side, SFN can be seen as a classical broadcasting network where strong echoes with huge delays are present. These “ echoes ” differ from short

©1999 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

term (real) echoes known as multipaths, whose delay would usually be about a few symbols (for example, an echo produced by a reflection implying a multipath difference of 300m is delayed by 1µs, that is 10 symbols). Figure 1 shows short term echoes (dashlines) due to reflections on structures.

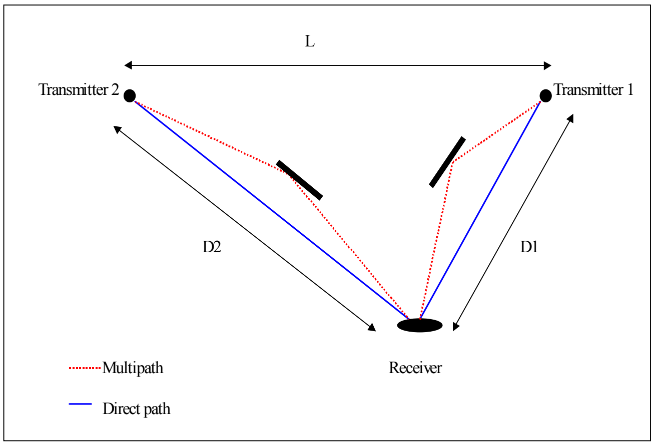

Fig1: Example of configuration in a SFN.

Assuming that symbol timing has been perfectly recovered and that carrier phase is well tracked, the equivalent Single-Input Single-Output discrete-time channel model is depicted as follows:

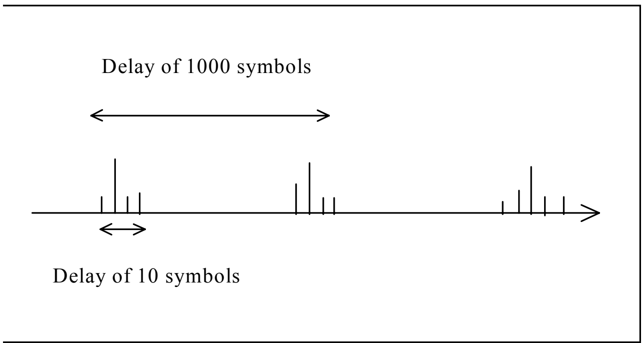

Fig2: Equivalent discrete-time channel model.

A classical single-sensor receiver with equalization requires an extremely high computational cost: that's why OFDM appears promising for SFN.

The idea of using OFDM can be simplified as follows : if we transmit the Fourier Transform of the symbols rather than the symbols themselves, the convolution performed by the echoes will be seen as simple multiplications on the original symbols. Hence, their effect will be easier to cancel.

From a practical point of view, most OFDM transmitters use Fast Fourier Transform (FFT) devices. For reasons that will not be detailed here, the length of the FFT should be at least about 8 times the maximum delay of the echoes. Hence 16384-points FFT or more is typical in the SFN context. The need to perform very large FFT is the major drawback of OFDM when used for SFN. Not only the computational load must be considered, but also the fact that, with such lengths, signal perturbations due to local oscillators fluctuations (phase noise, etc.) cannot be neglected. Also, since the number of subcarriers of OFDM is equal to the FFT length, these subcarriers become extremely close and a high precision on their frequencies is required.

3. An alternative approach : Array Processing

3.1. Overview

It is clear from above that OFDM is a natural candidate to solve problems related to SFN. Although OFDM is a very powerful method, the need to compute very long FFT is a drawback, especially when high symbol rates and long echoes are considered.

Hence it is interesting to study alternative approaches to OFDM. The receiver proposed in this paper is based on array processing. Figure 2 shows an overview of the approach. The antenna is composed of an array of N sensors. The signal received on each sensor goes through filtering, sampling, and conversion to baseband (downconversion).

Then, the number of sources, P, is estimated using a combination of AIC [1] and MDL [3] criteria, and the sources are localised using a source localisation algorithm, such as MUSIC. The angular localisation of the sources allows the construction of an estimated mixture matrix. The multiplication of the N-dimensional downconverted signal by the pseudo-inverse of this matrix provides a P-dimensional signal, in which each component corresponds (ideally) to a signal coming from a transmitter (or a strong short term echo), cleaned from interferences. Each component of this P-dimensional signal is then synchronised : Symbol Timing Recovery (STR) is performed using Gardner Criteria [2], and Carrier Phase is tracked by a Carrier Tracking Loop (CTL).

In order to improve the performances, the P components are then inter-synchronised (remember that there can be a delay larger than 1000 symbols between two paths) and summed (weighted summation). Inter-synchronisation is done by correlation. The weight of a given processing path is proportional to the current estimated SNR on this path.

After the summator there is a simple decision device and transcoder to recover the bit stream from the symbols. Although it was not done in our experiments, channel

©1999 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

IEEE-SPAWC, May 1999, Annapolis, Maryland, USA
(IEEE Workshop on Signal Processing Advances in Wireless Communications, pp. 341-344, Annapolis, Maryland, May 9-12, 1999)

coding can also be used on the bit stream in order to reduce the bit error rate.

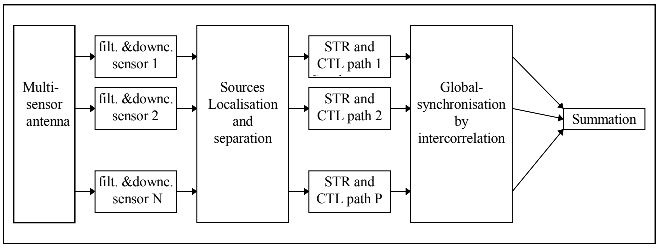

Fig3: Overview of the approach (filt. & downc. means filtering and downconversion)

3.2. Paths synchronisation and summation

In our experiments, we assumed that the symbol stream contains a sequence of L known symbols occurring with a fixed period. While this is not a requirement, the presence of such known sequences is true in most transmission protocols.

Let us note $\vec{z}$ the known sequence of length L, and $\vec{y}_n^{(i)}$ the vector containing the last L symbols available on the output of CTL path *i*. The normalised correlation (H means hermitian transposed) is computed by :

$$C_n^{(i)} = \frac{(\vec{y}_n^{(i)})^H \vec{z}}{\left\|\vec{y}_n^{(i)}\right\| . \left\|\vec{z}\right\|}$$

Detecting the peaks of this value on each path allows to globally synchronise the paths.

The CTL is able to lock the samples phase, but there remain a $k\frac{\pi}{N}$ ambiguity. *N* depends on the constellation used (*N*=2 for QAM). When a correlation peak is obtained (for *n=n0*), $\vec{y}_{n0}^{(i)}$ can be replaced by $\alpha.e^{jk\pi/N}\vec{z} + \vec{b}^{(i)}$ (where α is a positive real and $\vec{b}^{(i)}$ is a noise) in the equation above. Hence, the remaining phase ambiguity is easily estimated from the phase of the correlation peak value. If no gain control was performed before, α can also be estimated here.

Once the paths have been globally synchronised and the phase ambiguity has been cancelled, the symbols are summed. The summation weights are optimised in order to minimise the noise variance, under the constraint of the sum of the weights equal to 1. The noise variance on path *i* can be estimated by:

$$\sigma_i^2 = \left\|\vec{y}^{(i)} - \vec{z}\right\|^2 / L$$

where $\vec{y}^{(i)}$ contains the last L symbols on path i, after global synchronisation, gain control, and phase ambiguity cancellation. Since the result of summation is $\vec{y} = \sum_i K_i \vec{y}^{(i)}$, the resulting noise variance is $\sigma^2 = \sum_i K_i^2 \sigma_i^2$ (assuming independent noises). Using Lagrange multipliers, the solution is given by:

$$K_i = \frac{\lambda}{\sigma_i^2}$$

with $\lambda = \frac{1}{\sum_i \sigma_i^{-2}}$

4. Experimental Results

To illustrate the performances of the approach, let us consider the following configuration :

- 4 transmitters in the receiver vicinity, QPSK modulation
- transmitters angular localisation : 20°, 60°, 100°, 120°
- 4 short term echoes per transmitter
- N=6 sensors on the antenna
- SNR in the Nyquist band : 12 dB
- average relative power of the short term echoes with respect to direct paths : 1/10

In this case, the following results are obtained :

- Estimation of the number of sources : P=4
- Estimation of the angular localisation of the sources : 21° ,60° , 100° , 119°
- Bit Error Rate (BER) on path 1 before inter-synchronisation and summation: 6×10^{-3}
- BER on path 2 before inter-synchronisation and summation: 11×10^{-3}
- BER on path 3 before inter-synchronisation and summation: 14×10^{-3}
- BER on path 4 before inter-synchronisation and summation: 16×10^{-3}
- BER with the 4 paths inter-synchronised and summed : 10^{-5}

One of the major advantages of the proposed approach is its extremely low requirements on the precision of local oscillators. Figures 3 and 4 show the convergence of the STR (Symbol Timing Recovery) and CTL (Carrier Tracking Loop) with a relative error of 0.2% of the sampler frequency and a frequency error of the downconverter equal to 0.1% of the symbol frequency (such errors are high and would correspond to low-cost devices). Roughly speaking, STR and CTL are PI (Proportional-Integral) synchronisation loops. The figures

©1999 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.

show the value of the integral path accumulator with respect to the symbol number. When synchronisation is locked, these values converge, respectively, to the sampler frequency relative error and to the downconverter frequency shift (up to a scale factor). Good convergence is obtained in less than 1500 symbols (that is only 150µs at 10MHz).

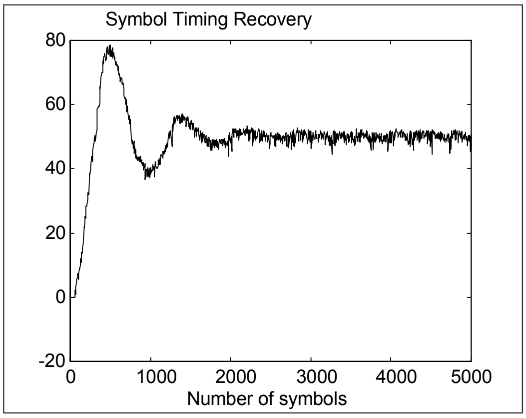

Fig4: convergence of STR

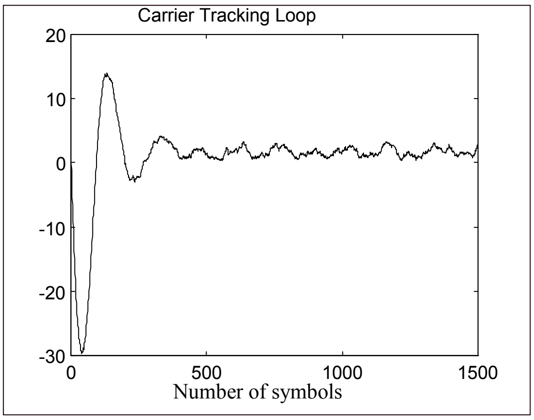

Fig5: Convergence of the CTL

5. Conclusion

An alternative approach to OFDM for Single Frequency Networks has been studied and experimented. The proposed approach is based on array processing, source separation, and signals synchronisation and summation.

One advantage of the method is to avoid problems due to the need of long packets in OFDM (with the implied requirements for extremely stable local oscillators and transmission channels, and for powerful FFT devices). A drawback of the proposed approach is the need of multisensor array, but, on the other hand, the requirements on the precision of electronic devices (local oscillators, etc.) are low.

References

[1] H. Akaike, “A new look at the statistical model identification”, IEEE Trans. On Automatic Control, vol 19, pp 716-723, 1974

[2] Floyd M. Gardner, “A BPSK/QPSK timing error detector for samplers receivers”, IEEE Transactions on communications, vol. 34, no 5, May 1986, pp 423-429

[3] J. Rissanen, “Modelling by shortest data description”, Automatica, vol 14, pp 465-471, 1978

[1] Pierre Magniez is now with ENST, 46 rue Barrault, 75634 Paris cedex 13, France

©1999 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.