Reducing Complexity Using Path Selection for Sequential Blind Beamforming for Wireless Communications

(*Invited paper*)

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Abstract — **In this paper, a path selection technique based on power level detection is introduced to our previously proposed MRC-Sequential Blind Beamforming method to reduce the receiver complexity. MRC-SBB mitigates the inter-symbol and intra-symbol interferences by recovering the signal and its integer and non-integer multiple replicas using jointly CMA, LMS and adaptive fractional time-delay-estimation filtering. While the resulting improvement using this method is proportional to the number of the detected paths and also the interpolation filters' complexity, targeting portable applications motivates us to propose a technique to reduce the power consumption while maintaining good performance. Thus, in this paper, a path selection technique based on the paths' power-level detection and digital filter dynamic activation is introduced to significantly reduce the power consumption of the hardware circuits. Simulations in different scenarios using path selection for MRC-SBB were carried out, and the obtained results validate the power consumption efficiency without sacrificing the BER performance.**

Keywords- Adaptive antenna arrays, CMA, LMS, fractional delay, adaptive canceller, inter-symbol interference, path selection.

I. INTRODUCTION

Multipath fading represents the main cause of quality degradation in wireless communications applied in harsh confined environments such as underground areas [1]. To provide a solution, adaptive antenna arrays (AAA) have been proposed [2-3]. Recently, an AAA with Sequential Blind Beamforming (SBB) has been proposed using jointly MCMA (Modified Constant Modulus Algorithm) [4], LMS and adaptive Fractional Time Delay Estimation (FTDE) filtering [4-7] to recover the desired signal and its integer and non-integer multiple replicas for received power maximization. A Maximum Ratio Combining (MRC) with hard decision feedback identification (DFI) [6-8] was also developed at the path diversity combining stage.

However, the performance obtained by this proposed path diversity technique is proportional to the number of its implemented path detection filters and their hardware complexity that will consequently increase the receiver power consumption. In some likely cases, these filters may detect a signal path with a very weak-power level due to fading or even only noise during the absence of the received path carrying the desired signal at the output of these filters. Therefore, an effective path selection should be introduced before the MRC combiner stage to manage efficiently the power consumption of the receiver and to eliminate the combining of undesired signals.

Moreover, reducing the power consumption and the complexity of embedded digital signal processor is an important issue for wireless mobile applications to provide small form factor handheld devices and to extend the battery life. Some techniques are used to minimize the power consumption in mobile applications [9]. In [9] a subset of paths is selected when the available number of correlators is limited. Motivated by the previous advantages, in this paper a reducing complexity using dynamically path selection technique based on power level detection is introduced to our previously MRC-SBB method to limit the power consumption without sacrificing the bit error rate (BER) performance. By detecting the power of the different received paths, the digital filters associated to every path are switched on and off to reduce hardware power consumption. In fact, based on paths' power-level detection, these filters can be dynamically deactivated for time periods, and activated again when it is needed. Consequently, instead of applying directly MRC over all estimated paths, a path selection processing is introduced to reject the paths with power below a certain threshold and simultaneously deactivate their filters. The performance of this path selection upgrade is evaluated in terms of BER performance compared to fully operated receiver.

This paper is organized as follows. In Section 2, a review of the MRC-SBB method is briefly described, and a reducing complexity by limiting the power consumption is presented using a path selection technique. Section 3 presents the performance of the MRC-SBB using path selection technique. Section 4 concludes this paper.

II. REDUCING COMPLEXITY USING PATH SELECTION TECHNIQUE FOR MRC-SBB

A. *Signal model and MRC- SBB overview*

Consider a uniform linear array of N omni-directional-antenna elements receiving L multipath signals. The received signal $x_m(k)$ at the m-th antenna can be expressed as:

$$x_m(k) = \sum_{i=1}^{L} \alpha_i(k) \cdot s(k-\tau_i) \cdot e^{-j\pi(m-1)\sin(DoA_i)} \cdot e^{-2\pi f_D \cdot k} + \eta_m(k), \quad (1)$$

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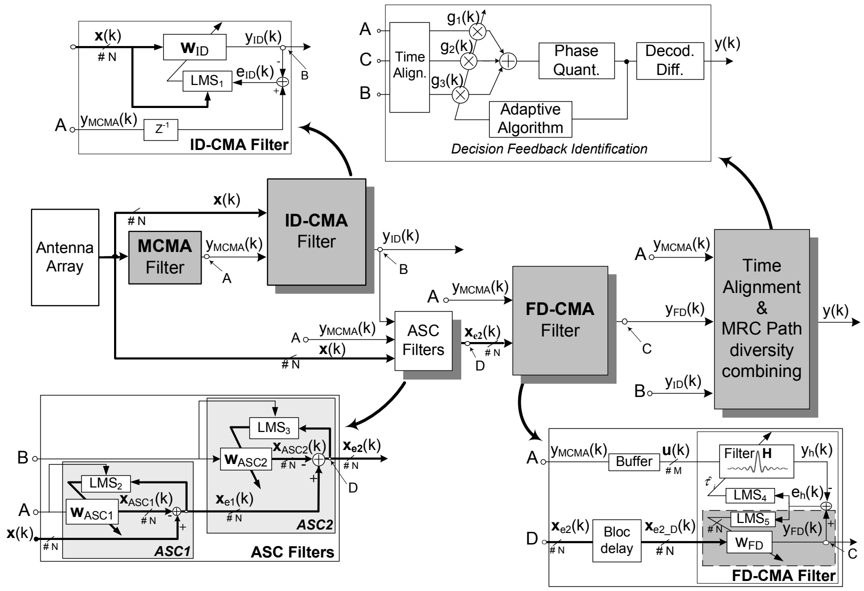

Figure 1. Proposed SBB Algorithm.

where, $\alpha_i(k)$ are the complex gains of the Rayleigh fading rays (with uniformly distributed phases φ_i between 0 and 2π) of the i-th path; $\alpha_i(k)e^{-2\pi f_D \cdot k}$ are of Jakes' model with f_D as maximum Doppler spread, $s(k)$ is the desired source sequence, drawn from alphabet members $A_M=\{a_1,\ldots,a_M\}$, L is the number of the multipath signals, τ_i is the time path arrival (TPA) for the i-th path, DoA_i is the direction of arrival of the i-th path and $\eta_m(k)$ are additive white Gaussian noise processes with variance σ_n^2 at the m-th receive antenna. For convenience, the array is assumed to be uniform and linear with inter-element spacing $d=\lambda/2$, where λ is the wavelength at the operating frequency.

For the sake of simplicity and for illustration purposes, the following study is carried out using a three-path channel model where the TPAs are given by $\tau_1 = 0$ (assumed to be the strongest path), $\tau_2 = \tau < T_s$, and $\tau_3 = T_s$. In summary, this method is implemented using three sequential filters, as depicted in Fig.1. The first filter (MCMA) is used to estimate the strongest path while its weights are adapted using MCMA [4-7]. The output of this filter is fed into both the Integer Delay-CMA (ID-CMA) [4] and Fractional Delay-CMA (FD-CMA) filters [5]. Path coming with a delay that is multiple integer of the sampling interval ($\tau_3 = T_s$) is estimated using an ID-CMA filter adapted using LMS with the CMA delayed output as a reference signal. And the path coming with fractional delay ($\tau_2 = \tau$) is estimated using an FD-CMA filter adapted using LMS and FTDE, the latter being implemented by the truncated *sinc*-interpolation filter. To ensure that the FD-CMA filter detects the path arriving with a fractional delay and not the others, adaptive signal cancellers (ASC) are used to extract sequentially the estimated signal contributions from the received signal vector $\boldsymbol{x}(k)$. However, the extracted paths y_{MCMA}, y_{FD} and y_{ID}, estimated by the MCMA, FD-CMA and ID-CMA filters, respectively, possess a common phase ambiguity, since they are sequentially extracted using y_{MCMA} as a reference signal. As a result, a combination based on a simple addition of the estimated paths can only be constructive and it represents the output of a coherent Equal Gain Combiner (EGC). For a Differential Binary Phase Shift Keying (DBPSK) modulation scheme where the common phase ambiguity is actually a sign ambiguity, an EGC is equivalent to MRC. For higher order modulations such as Differential Quadrature Phase Shift Keying (DQPSK), where the common phase ambiguity is an unknown angular rotation, more substantial improvement compared to EGC has been obtained by implementing coherent MRC with hard DFI, which strives to force this common phase ambiguity to known quantized values that keep the constellation invariant by rotation [8], thereby allowing coherent demodulation and MRC detection.

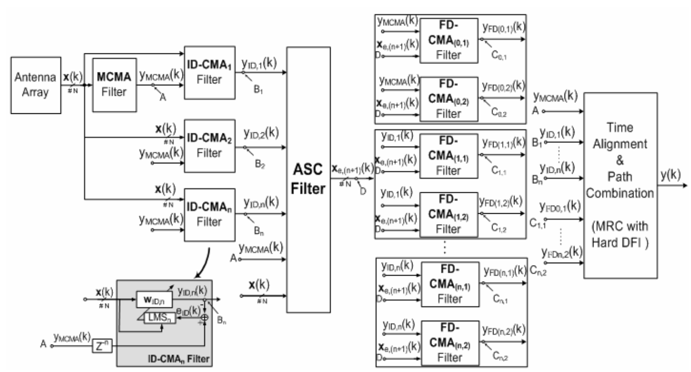

Figure 2. MRC-SBB generalized architecture.

B. Path selection technique

In a generalized architecture of our proposed MRC-SBB method, it is considered that the maximum number of paths is known a priori and hence, the required number of ID-CMA$_m$ and FD-CMA$_{(i,j)}$ filters are implemented to resolve the different paths as illustrated in Fig. 2. Here, we expect to receive n paths arriving with integer delays, where the remaining paths are arriving with fractional delays. In the general case, n ID-CMA$_m$ filters ($1\leq m \leq n$) with two inputs are implemented, where the 1st input is connected to the received signal vector $\mathbf{x}(k)$, and the 2nd input is connected to a delayed replica (Z^m) of the MCMA filter output in order to detect the paths arriving with a delay equal to $\tau = mT_s$,. Concerning the FD-CMA$_{(i,j)}$ filters, Fig.2 shows the case where two fractional-delay paths can be detected in each symbol duration (p=2).

To reduce the receiver power consumption, a path selection technique based on power level detection at the output of the implemented filters is introduced by applying path selection technique to turn off the filters with ineffective outputs.

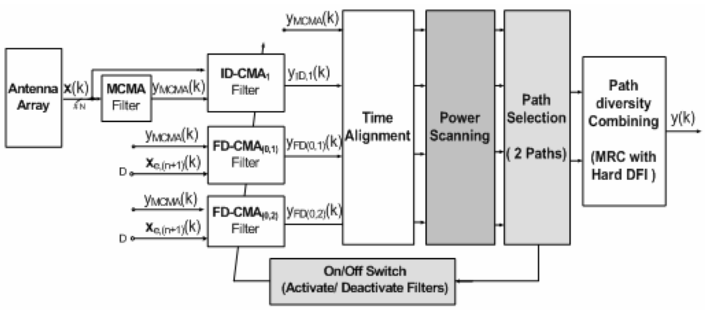

Figure 3. Path selection technique based on power level detection introduced in MRC-SBB for n=1 and p=2.

For the sake of simplicity and for illustration purposes, the following study is carried out using a four-path channel model where the TPAs are given by τ_1=0, τ_2 and τ_3 are smaller than T_s, and $\tau_4 = T_s$. As shown in Fig. 3, the MCMA, FD-CMA$_{(0,1)}$, FD-CMA$_{(0,2)}$ and ID-CMA$_1$ filters are implemented to detect the paths with delays τ_1, τ_2, τ_3 and τ_4, respectively. The introduced path selection technique, represented in Fig.3 by the gray blocks, selects in this illustrative example only the two main signal paths at the input of the MRC stage. In this technique the *Power Scanning* block computes the paths' power-level by estimating their instantaneous average powers or by computing the inter-correlation coefficients between y_{MCMA} signal and the estimated filters' outputs, i.e ID-CMA$_m$ or FD-CMA$_{(i,j)}$ filter as explained later. The *Path Selection* block selects the strongest path based on predefined criteria and consequently commands the *On/Off Switch* block to turn on/off dynamically the input filters.

1)-Path selection technique based on average instantaneous power estimation:

At the output of each ID-CMA$_m$ and FD-CMA$_{(i,j)}$ filter, the *Power Scanning* block estimates the average instantaneous power during a period $K.T_s$, given by:

$$P_l(k) = \frac{1}{K}\sum_{n=1}^{K}\left|y_l(n)\right|^2, \qquad (2)$$

where y_l represents the output of either the ID-CMA$_m$ or FD-CMA$_{(i,j)}$ filter, i.e. $y_l(n)=y_{ID,m}(n)$ ($1\leq m\leq n$) or $y_l(n)=y_{FD(i,j)}(n)$,

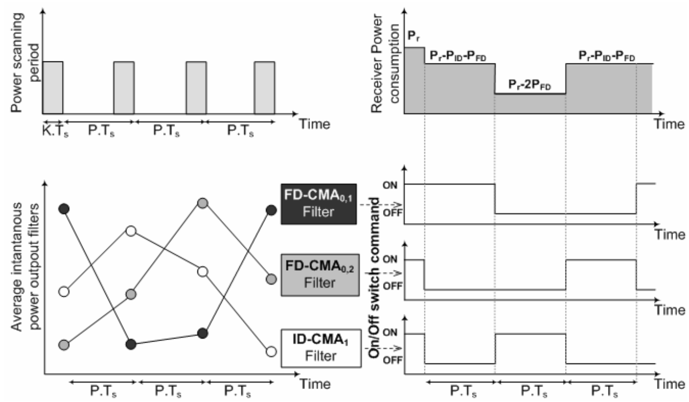

Figure 4. An example of path selection technique and on/off switch introduced in MRC-SBB for n=1 and p=2.

($1\leq i\leq n$ & $1\leq j\leq 2$), respectively, and K represents the scanning period.

Fig.4 illustrates the power-signal level evolution diagram in the case of a four-path channel model. The strongest paths are selected by the *Path Selection* block and their relative filters will be active during a period of $P.T_s$, ($P>K$) while those of the rejected paths will be deactivated by the *On/Off Switch* block. However, to verify if that the selected paths remain the strongest ones, all the filters are activated again for a new power estimation session at $(P\text{-}K)T_s$ during a $K.T_s$ duration (see Fig. 4). For instance at $(P+K).T_s$, the filter ID-CMA$_1$ will be on and the filters FD-CMA$_{(0,1)}$ and FD-CMA$_{(0,2)}$ will be off. In this case the *Path Selection* block transmits to the MRC block only the ID-CMA$_1$ path while the second one is always the y_{MCMA} path.

Suppose that the receiver consumes a total power P_r when all filters are active and that P_{ID} and P_{FD}, (where $P_{ID}<P_{FD}$), are respectively, the power consumed by the ID-CMA$_m$ and FD-CMA$_{(i,j)}$ filters. Fig. 4 shows that power consumption can be greatly reduced by using dynamic path selection technique based on power level detection.

2)-Path selection technique based on inter-correlation coefficient estimation:

Since the MCMA filter detects the strongest path, the inter-correlation coefficient between this signal and the output of the other filter after time alignment, as given in (3), will have a maximum value at k = 0. By comparing the inter-correlation coefficients resulting for the different paths, an effective path selection can be performed:

$$R_l(k) = \frac{1}{K}\sum_{n=1}^{K}\left(y_{MCMA}(n+k-\tau)\cdot y_l(n)^*\right), \qquad (3)$$

where τ represents the time alignment between the two paths.

III. SIMULATION RESULTS

In this section, simulation results are presented to assess the performance of the introduced dynamically path selection technique applied to the MRC-SBB. A two-element array with half-wavelength spacing is considered. A DQPSK desired signal is propagated along seven multipaths to the antenna array while the interferences and noise are simulated as white Gaussian noise. The first path is direct with time path arrival delay $\tau_1 = 0$. The second and third paths arrive with delays τ_2 and τ_3 smaller than the sampling interval, respectively. The forth path arrives with delay $\tau_4 = T_s$ while the fifth and sixth paths arrive, respectively; with delays τ_5 and τ_6 smaller than $2.T_s$ (belong to $[T_s, 2T_s]$). And the last one arrives with $\tau_6 = 2T_s$. The channel model is Rayleigh fading with a Doppler shift f_d = 20Hz. For both selection techniques (Average power level & inter-correlation coefficient), the threshold value is set to 0.01 for a normalized power. The figure of merit is the SNR required to guarantee a BER below 0.001. For more exhaustive comparisons, the path selection decision was curried out with different cases as shown in Table 1. A benchmark comparison with AAA using MCMA and using EGC-SBB is also provided.

TABLE 1
PATH SELECTION CRITERIA

Case	Path selection case	Acronym
# 1	Based on threshold value using MRC	Thresh_MRC-SBB
# 2	4 high power paths using MRC	4 High_MRC-SBB
# 3	All path are selected & combined using MRC	All_MRC-SBB
# 4	All path are selected & combined using EGC	All_EGC-SBB

Figures 5 and 6 show the measured BER performance versus SNR for SBB using average instantaneous power and inter-correlation estimation, respectively, for different path selection cases given in Table 1. For both figures, it can be noted that the path selection technique to reduce the receiver complexity preserves the performance obtained with fully operational receiver.

IV. CONCLUSION

In this paper, a dynamically path selection to reduce the receiver complexity has been introduced to our previously MRC-SBB to manage the power consumption without sacrificing the BER performance. In fact, instead of directly applying MRC over all estimated paths, a path selection processing is introduced to reject the ineffective paths and switch off their related filters during a predefined period. In this contribution, two path selection techniques based on path' power detection and inter-correlation coefficient have been presented. For both techniques, the results are approximately the same and preserve the performance achieved with a fully operational receiver.

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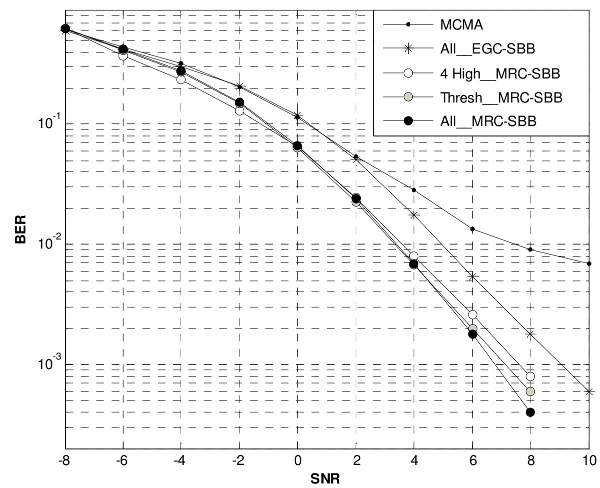

Figure 5. BER performance versus SNR using SBB based on average instantaneous power level with different path selection cases.

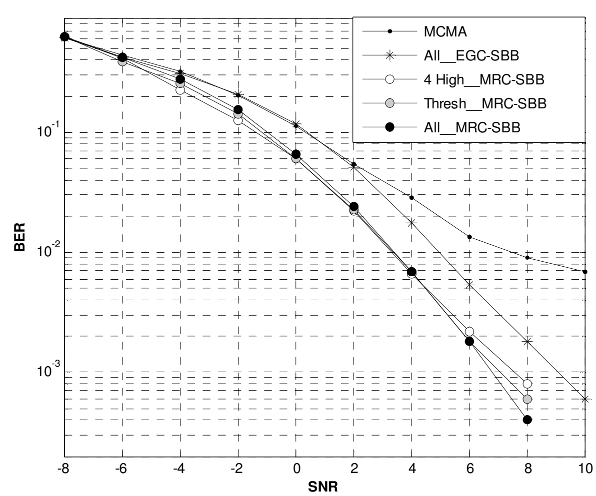

Figure 6. BER performance versus SNR using SBB based on Inter-correlation coefficient with different path selection cases.