Faster approach for Active Interference Cancellation in MB-OFDM Cognitive Radio

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***Abstract*—When the primary user falls in between the band of contiguous tones used for OFDM, the secondary user has an option to either switch to a different frequency range or stop using the particular tones where the narrowband primary user dwells. In the latter case, applying a simple analog or digital notch filter is the simplest but not a favourable approach, due to the power wastage. Simply turning off the tones in OFDM introduces inter-carrier interference, limiting the notch depth to 5-10 dB[1]. There are many methods like the ones discussed in [1], [2] , [3] for achieving a deeper notch in the null tones, at the sacrifice of additional tones adjacent to the null tones. This paper revisits the method described in [1] , but re-implemented using a faster technique for computing the Moore-Penrose Inverse of the interpolated sub matrix derived from higher order IFFT.**

***Keywords*— Active Interference Cancellation, Cognitive Radio, real-time, OFDM.**

I. Introduction

Multiband OFDM, finds an irreplaceable use in cognitive radios, due to its flexibility and its immunity to the problems arising out of multipath. Since by design, a Cognitive radio must incorporate a coexistence mechanism for, which should be able to detect a nearby victim/primary user's radio, (or compliance to the regulatory rules of the region) and reducing its interference below the sensitivity threshold. The latter mechanism is much discussed and a matured topic in the academic community. The concept of Active interference cancellation using adjacent tones spawns from [1], and is among the most fundamental technique upon which further methods have been developed. This paper deals with the fundamental concept presented in [1], and implementation wise, make it computationally cost effective and also faster, based on the method described in [2] for computing the pseudo-inverse of a matrix.

Section 2 discusses the fundamentals of Active Interference Cancellation(AIC) technique using tone cancellation. Section 3 discusses the full rank Cholesky factorization method used for computing the pseudo-inverse of a matrix and compares the performance of the discussed algorithm with other similar algorithms for computing the pseudo-inverse. Section 4 presents the implementation of the method discussed in Section 2, using the method discussed in Section 3.

II. Active Interference Cancellation

For example sake, let us consider a situation where we have a OFDM symbol of 128 tones and we need to turn off the tone #85, 86 and 87 of the OFDM band, just the way this method was illustrated in [1].

When the information data is denoted by $(k), k = 0,1,2,\ldots,127$, the transmitted OFDM signal is given by

$$x(n) = \sum_{n=0}^{127} X(k)\exp(j2\pi\frac{nk}{128}) \qquad (1)$$

To compute the interference between the tones, we up-sample the corresponding spectrum(four times) into one which has four tones for each tone present in the original spectrum. The up-sampled spectrum denoted by $Y(l), l = 0,1,2,\ldots,4*128-1$

$$Y(l) = \frac{1}{128}\sum_{n=0}^{127} x(n)\exp(j2\pi\frac{n}{128}\frac{l}{4}) \qquad (2)$$

Combining the equations (1) and (2), we obtain that X and Y are related as

$$Y(l) = \frac{1}{128}\sum_{n=0}^{127}\sum_{k=0}^{127} X(k)\exp(j2\pi\frac{n}{128}(k-\frac{l}{4})) = \frac{1}{128}\sum_{k=0}^{127} X(k)P(l,k) \qquad (3)$$

where $P(n,l)$ is the transform kernel.

Upon analysing we can find a lot of spill over of power from adjacent tones intp the turned off tones #85, 86 and 87. So, to cancel this, we define two special tones at the edge of the interference band as shown in Fig.1. These special tones are called Active Interference Cancellation(AIC) tones. Now to compute the two tones, as follows.

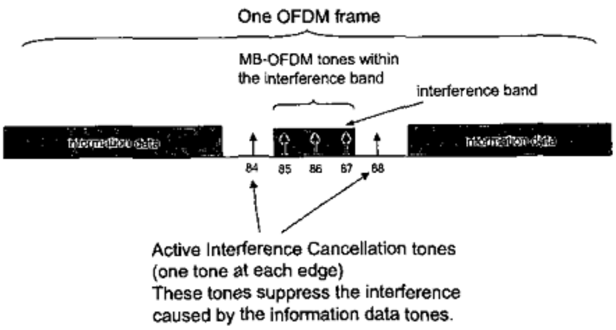

Fig 1 Definition of AIC tone position

Let us take the vector d_l, denoting the interference to the turned off namd, where $d_l(1)$, $d_l(4)$ $d_l(8)$ correspond to MB-OFDM tones #85, 86 and 87. We then add two tones on the edge outside these three tones, and try to cancel the interference inside the interference band using the total of five tones. The vector d_l is given by,

$$d_l = Pg \tag{4}$$

where P is the kernel defined in equation (3) and g is the vector of the information data tones with $X(84)$ to $X(88)$ turned off(zeroed).

In order to cancel interference within the band, we need to generate the negative interference signal using the tones $X(84)$ to $X(88)$.Again using the relation (3), abovem setting all the X to zero except for $X(84)$ to $X(88)$, the quation to be solved is given by

$$P_l h = -d_l \tag{5}$$

where h is the column vector of (X984),....X(88)) and P_l is the small kernel derived from P by limiting the index according to h and d_l. Thus$P_l$is a 9×5 matrix.

Here, h is our desired tone values. However, (5) cannot be solved in the straightforward way because matrix P_l is not invertible. Hence we seek the minimization of

$$e^2 = \|P_l h + d_l\|^2 \tag{6}$$

which leads to

$$h = -(P_l^T P_l)^{-1} P_l^T d_l = -W_l d_l \tag{7}$$

This minimum mean-squared solution is also known as the Moore-Penrose generalized inverse [5]. Now combining (4) and (7), h is given by,

$$h = -W_l P g = -W_2 g \tag{8}$$

where W_2 is a 5×128 matrix.

III. Full rank Cholesky factorization based Computation of MP Inverse Matrices:

The Moore-Penrose inverse of $m \times n$ matrix G is the unique $n \times m$ matrix G^+ with the following four properties.

$$GG^+G = G, GG^+ = G^+, (GG^+)' = GG^+, (G^+G)' = G^+G \tag{10}$$

where G' denotes the transposal(real case) or the adjoint(complex case) of matrix G. Whenever G is of full rank (n), the Moore-Penrose inverse reduces to the usual pseudo-inverse:

$$G^+ = (G'G)^{-1}G' \tag{11}$$

However, when G is rank deficient, the computation of G^+ is more complex. There are several methods for computing the Moore-Penrose inverse matrix. The most commonly used is the Singular Value Decomposition(SVD) method, that is implemented, for example, in Matlab as "*pinv*" function. However, this method is not of practical use for computationally constrained real-time applications, due to its computational cost. However the method described in [4] computes a full rank Cholesky factorization of $G'G$ and the inversion of $L'L$, where L is of full rank r, $r \times m$ matrix, derived from the unique upper triangular matrix S, obtained using the simple Cholesky factorization of singular matrices, with its zero rows removed.

Thus the $G+$ matrix is computed as:

$$G^+ = G' * L * M * M * L'; \quad when\, m < n \tag{12}$$
$$G^+ = L * M * M * L' * G'; \; when\, m >= n \tag{13}$$

where $M = (L' * L)^{-1}$

	Greville's method	SVD method (Matlab *pinv*)	Full rank QR (by GSO)	Iterative (of order 512)	*geninv*
$n = 32$	0.015	0.025	0.006	0.019	0.007
$n = 64$	0.296	0.044	0.035	0.141	0.022
$n = 128$	1.734	0.363	0.453	0.664	0.105
$n = 256$	17.092	5.433	3.795	4.158	0.768
$n = 512$	169.850	49.801	29.197	29.286	6.445
$n = 1024$	2160.10	373.90	240.22	232.688	54.14

Table 1 Computation time(in seconds) of the Moore-Penrose inverse of random rectangular rank-deficient real matrices y four usual algorithms and the geninv, as function of matrix size

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IV. AIC Implementation

Based on the simulation results in Matlab, the code [6] which implements the AIC technique discussed in [1], using the technique discussed in [4], shows a performance of 542 milliseconds on average, when using a precomputed kernel, P.

It must be noted that the practically achievable notch depth depends on the input data sequence. Also, it must be noted that using the plain AIC using side tones, achieves up to $-30dB$ of notch depth on average, when the input data symbols' energy has a uniform distribution $[0.95,1]$.

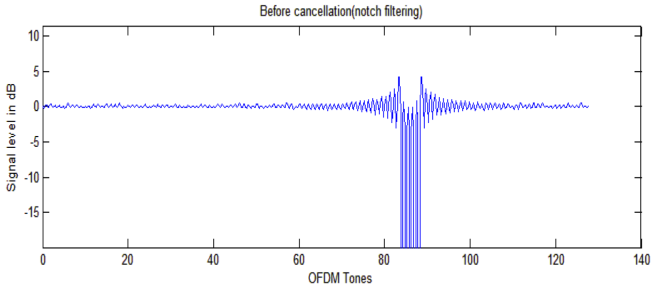

Fig 2 Before AIC (only notch filtering)

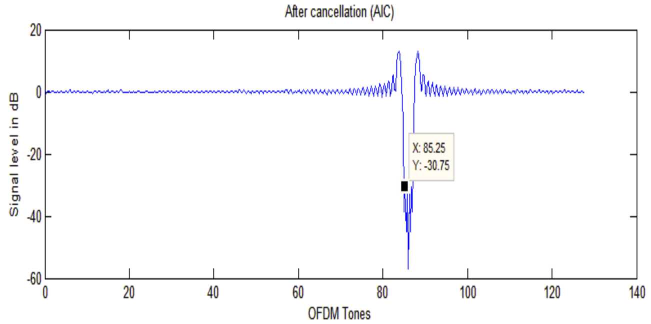

Fig 3 After AIC

V. Conclusion

Thus the implementation [5] of [1], using [4] for computing the pseudo inverse, presented in the previous section, has a potential to be computed in real-time, within the given computational constraints, for all practical purposes requiring AIC.

References

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[6] GitHub Repository of the implementation: https://github.com/dsriram/AICMatlabCode