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Obtaining reliability values from nonparametric receiver: the "optimal" parameter choice [1]

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Abstract. In what follows a coded DHA FH OFDMA system employing short block MDS codes as inner codes in time domain and nonparametric detector is considered. For the system under consideration dependencies of the probability of erroneous decoding and denial probability for the inner codes on the detector parameter that is used to compute reliability values for the symbols of inner code are investigated.

1 Introduction

Interference mitigation is one of the key issues in modern telecommunication systems design. This is mainly due to the fact that interference can be caused by different factors: authorized users' activity in a multiple access system (multiuser interference, MUI), signals transmitted by the users of other telecommunication systems operating within the same frequency bands or intentional jamming. If the interference is severe traditional reception techniques turn out to be ineffective due to low reliability of the computed decision statistics. In this case nonparametric detection techniques (e.g. [1–3]) are to be applied. In what follows a coded DHA FH OFDMA system employing order-statistics based detector proposed in [5] and relatively short MDS block codes as inner codes in time domain is considered.In this paper a coded DHA FH OFDMA system employing short block MDS codes as inner codes in time domain and nonparametric detector is considered. It is aimed at finding out how sensitive is the detector under consideration to parameters choice.

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2 A DHA FH OFDMA system: Transmission and Reception

Let us consider a multiple access system in which K active users transmit information via a channel split into Q identical nonoverlapping subchannels e.g. by means of OFDM. In what follows it will be assumed that information that is to be transmitted is encoded into a codeword of a q-ary (n, k, d) block code $(q < Q)$. This code will be further on referred to as "inner code in time domain" Whenever a user is to transmit a $q-$ary symbol it places 1 in the position of the vector $\bar{a}_g$ corresponding to the symbol in question within the scope of the mapping in use (in what follows it will be assumed that all the positions of the vector are enumerated from 1 to Q, moreover for the sake of simplicity and without loss of generality we shall assume that the 1st subchannel corresponds to 0, the 2nd subchannel corresponds to 1 and so on). Thus each $q-ary$ symbol to be transmitted is mapped in to a weight 1 binary vector which will be referred to as "inner code in frequency domain" (the construction under consideration is the Kautz-Singleton construction for binary superimposed codes [4]). Then a random permutation of the aforesaid vector is performed and the resulting vector $\pi_g(\bar{a}_g)$ is used to form an OFDM symbol (permutations are selected equiprobably from the set of all possible permutations and the choice is performed whenever a symbol is to be transmitted). The transmission technique in question can be can be interpreted in the following way: assume that whenever a certain user is to transmit a symbol it randomly chooses q out of Q available subchannels (subcarriers). Since the list of the subchannels that can be used to transmit a signal (or a hopset) is allocated to each user in a dynamic fashion the technique under consideration is referred to as Dynamic Hopset Allocation Frequency Hopping OFDMA (DHA FH OFDMA).

Therefore in order to transmit a codeword a user is to transmit n OFDM symbols. A sequence of OFDM symbols corresponding to a certain codeword that has been sent by a certain user will be referred to as a frame. Note that frames transmitted by different users need not be block synchronized, i.e. if within the time interval a certain user transmits a frame that corresponds to a codeword, symbols transmitted by another user within the same time period do not necessarily all comprise one codeword. Moreover, it will be assumed that transmissions from different users are uncoordinated, i.e. none of the users has information about the others. In what follows we shall assume that all users transmit information in OFDM frames and the transmission is quasisynchronous. In terms of the model under consideration this assumption means that transmissions from different users are symbol synchronized.

Within the scope of a certain codeword reception the receiver is to receive n OFDM symbols corresponding to the codeword in question. Note that the receiver is assumed to be synchronized with transmitters of all users. Therefore all the permutations done within the scope of transmission of the codeword in question are known to the user. The receiver measures energies at the outputs of all subchannels (let us designate the vector of the measurements as b_g where g is the number of the OFDM symbol) and applies inverse permutation to each vector b_g corresponding to the respective OFDM symbol thus reconstructing the initial order of elements and obtaining vector$\tilde{b}_g = \pi_g^{-1}(b_g)$. Let us consider a matrix X that consists of vectors $\tilde{b}_g = \pi_g^{-1}(b_g)$ that correspond to the codeword of inner code . Let us consider the submatrix $\Re = [\bar{\Re}_1, \bar{\Re}_2, \ldots, \bar{\Re}_n]$ (here $\Re$ is submatrix corresponding to the q first rows of the matrix X_c and each vector $\bar{\Re}_s$ is the height q column vector corresponding to the $s-th$ symbol of the codeword). Please note that $\Re$ provides all the information necessary to decode the codeword of the inner code.

3 Detection

The detection procedure that will be considered in this section can be decomposed in two successive procedures: reliability values computation and decoding. Foremost let us consider the former procedure. In [4] the following reception technique has been proposed (in what follows it will be referred to as α detection): let us assume that each column of the matrix X_c is sorted in the descending order. Let us designate the $t-th$ element of the vector α_j obtained by sort the $j-th$ column of the matrix X_c in the descending order by $\alpha_j(t)$. Let us consider the matrix D^t:

$$D^t(i,j) = \begin{cases} 1 & X_c(i,j) \geq \alpha_j(t) \\ 0 & X_c(i,j) < \alpha_j(t). \end{cases} \tag{1}$$

Each column of the matrix D^t contains exactly t nonzero entries. The nonzero entries in a certain column correspond to the elements of the respective column of matrix the $\Re$ having values greater or equal than $t-th$ q quantile of this column. The matrix D^t is the matrix of the reliability values for the detector under consideration. Let us assume that the user under consideration transmits a codeword v_m and within the scope of the mapping in use this vector is mapped into a matrix $X^m = [\bar{X}_1, \bar{X}_2, \ldots, \bar{X}_n]$. For the sake of convenience let us define a row vector V_m of the indices corresponding to the symbols of the codeword v_m:

$$\forall\, s = 1:n \quad X_s^m(l) = \begin{cases} 1 & l = V_m(s) \\ 0 & l \neq V_m(s) \end{cases} \tag{2}$$

where $X_s^m(l)$ is the lth element of the sth column of the matrix X^m and $V_m(s)$ is the sth element of the vector V_m.

Let us now consider the decoding procedure. The reliability value for the mth codeword is given by:

$$S_m = \sum_{s=1}^{n} Y_s(V_m(s)) \tag{3}$$

where $Y_s\left(V_m\left(s\right)\right)$ is the $V_m\left(s\right)$th element of the vector $\bar{Y}_s$.

The decoding rule boils down to choosing codeword number $m^* = \arg\ \max\limits_{m}\left(S_m\right)$ if m^* is unique (i. e. $\forall\ m = 1 : M, m \neq m^*\ \ m^* > m$, where $M = |C|$) otherwise a denial decision is taken.

4 Simulation

The probability of correct detection is predetermined by both the value of the parameter α that is used to compute reliability values and the parameters of the inner code. In what follows the influence of these parameters on the performance of the detector is investigated. However due to the importance for practical applications some restrictions some restrictions must be put. Since the decoding of inner code boils down to exhaustive search small to moderate codebook sizes are to be considered. Since under severe interference (i.e. the case for which the detector under consideration has been designed) the inner code cannot provide probabilistic characteristics meeting the requirement imposed by modern communication systems concatenated coding is to be employed. Therefore the rate of the inner code in time domain predetermines the overall transmission rate of the code construction. Thus very low rate inner code choice is undesirable and relatively small code lengths are to be considered. Since were are interested in minimizing the probabilities of erroneous decoding and denial MDS code (in particular codes obtained by puncturing (15,2,14) Reed-Solomon code) will be used as inner code in time domain. To investigate the effect of inner code length (rate) and the value of the α parameter variation on the performance of the detector under consideration the following scenario will be considered: it will be assumed that the user under consideration transmits in a system with $Q = 4096$ orthogonal subcarriers employing the transmission technique considered above and apart form the user under consideration K interfering signals are transmitted in the system under consideration. Hereinafter it will be assumed that each interfering signal has the same form as that of the user under consideration but its power at the receiver end is $\kappa = 10^4$ times higher than that of the signal of the user under consideration. Moreover it will be assumed that apart from narrowband interfering signals the received signal is influenced by the wideband interference that will be modeled as an Additive White Gaussian Noise characterized by signal-to-noise ratio $SNR = 10 * log_{10}(\frac{E_s}{E_N})$ where E_s is the energy of the signal transmitted by the user under consideration (at the receiver side) and E_N is noise energy (please note that E_N is noise energy in the entire band whereas E_s is the energy in the effective band occupied by the transmitted signal. Since the effective bandwidth is much smaller than the entire one SNR values can take very large negative value). To exemplify a typical performance of inner code decoder for different values of the parameter α dependencies of P_e (probability of erroneous decoding, shown with solid lines) and P_d (denial probability, shown with dashed lines) on the SNR value in dB

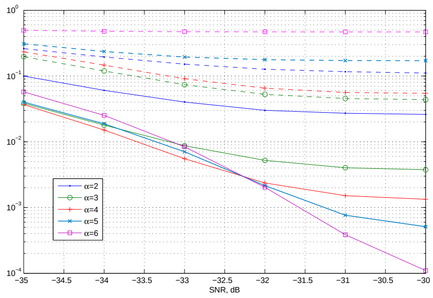

Figure 1: Dependencies of P_e (probability of erroneous decoding, shown with solid lines) and P_d (denial probability, shown with dashed lines) on the SNR value in dB (for rate 1/3 inner code and K=200)

for different inner codes (namely (6,2,5) and (8,2,7) codes over GF(16)) and K=200 are shown.

As can be seen from Fig.1 and Fig. 2 the probabilities in question are not monotonic functions of α. In fact there exists an optimal value of this parameter. In particular for smaller block lengths (or relatively high inner code rates) the values $\alpha = 3$ and $\alpha = 4$ yield smallest denial probabilities. Moreover the value $\alpha = 4$ provides minimal probability of erroneous decoding for the SNR zone corresponding to drastic interference. Please note that even though there exists a region where smaller values provide lower probability of erroneous decoding denial probabilities for those values are substantially higher. For longer inner code (i.e. inner code with lower rate) the situation is almost the same (apart form the fact that the region were higher values of α provide smaller probabilities of erroneous decoding start about 1 dB later as compared to the previous case). Thus we can deduce that choosing $\alpha = q/4$ provide minimum values of both denial probability and probability of erroneous decoding for a wide range of system parameters.

5 Conclusion

In what follows a coded DHA FH OFDMA system employing short block MDS codes as inner codes in time domain and nonparametric detector has been considered considered. Simulation results obtained demonstrate that for the detector under consideration there exists a value of the parameter α that provides optimal (or almost optimal) probabilistic characteristic for a wide range of parameters that can be of interest in practical applications.

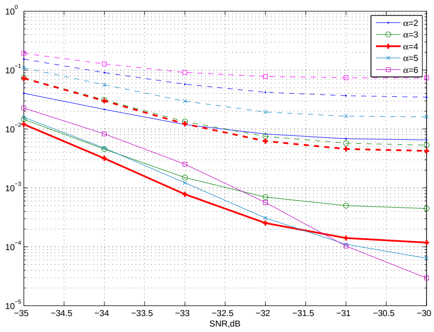

Figure 2: Dependencies of P_e (probability of erroneous decoding, shown with solid lines) and P_d (denial probability, shown with dashed lines) on the SNR value in dB (for rate 1/4 inner code and K=200)

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