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Overloading the Capacity of Multiple Access Channel

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ABSTRACT

Limited availability of spectrum has always motivated the researchers to focus on various multiple access coding and decoding techniques. Such techniques not only help in having more users but also assist in error control. The complementary weight based coding (CWC) effectively allows the same medium or channel to be shared by more than one user without any further subdivision in time, frequency or orthogonal codes in order to have orthogonality. The coding and decoding is based on assigning separate predefined weights to different users so as to have a distinction in their respective transmitted symbols. A simple multi level threshold logic detector (TLD) with hard decision (HD) logic is used for decoding purpose. The effectiveness of the proposed technique is tested in the presence of AWGN channel condition.

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1. INTRODUCTION

Overwhelming demand of wireless cellular service and higher cost of limited spectrum has been the prime source of motivation for the researchers to go for some effective alternatives of the conventional multiple access techniques. The multiple access channel (MAC) as shown in Fig 1**,** is a transmission medium, where there are T independent resources transmitting data to T different receivers over a common channel. The individual users signal will interfere with each other. But various techniques have been proposed in the literature [1-7] to accommodate more number of users within the limited spectrum. The coding and decoding techniques involved in [1-7] bear the capacity to decode the transmitted data with acceptable error performance over noisy channel condition. In this paper, the complementary weight based coding (CWC) scheme has been proposed for the MAC, where each of the T users gets assigned a predefined complementary weight (CW). Use of the complementary weights splits the newly generated symbols or alphabets to separate space over a one-dimensional multilevel constellation (S_k). Selection of proper CW values makes it possible to decode the information bits of the T users with better error protection capability. Previously in literature [7], superposition coding for MAC has been proposed involving weighing of the users signal for high and low transmission power simultaneously depending on their distance from the base station. Here it has to be kept in mind that, the selection of weights and method of decoding in transmission with superposition coding is completely different from the proposed CWC. Unike superposition coding, the decoding involved in CWC is simply based on few comparisons at the threshold decoder. Where as in former case, it demands T stages of separate iterations for the detection of T users completely, which adds complexity to the system design.

The following sections contain the detailed explanation of the CWC multiple access scheme. Section-2 describes the principle of CWC. In Section-3, the decoding based on hard decision (HD) logic has been emphasized. Section-4 deals with the simulation results of the proposed technique over AWGN channel followed by conclusion in section-5.

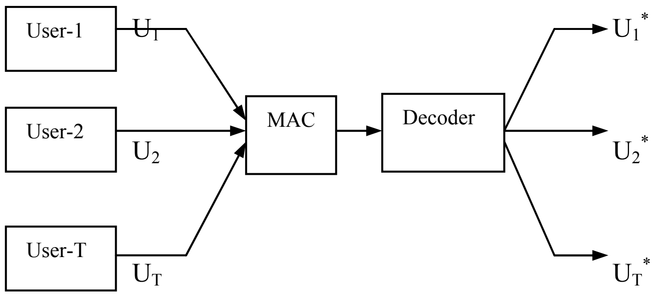

Figure 1. Block diagram of a simple T-user MAC

Table-1: Constellation for T=2 user MAC

U_1	U_2	$S_k=U_1+U_2$
-1	-1	-2
-1	1	0
1	-1	0
1	1	2

S_k=0 for (U_1 U_2)=(-1 1) or (1 -1) creates ambiguity at the decoder

2. COMPLEMENTARY WEIGHTBASED CODING (CWC)

The fundamental concept of CWC starts with the grouping of data from T different users to generate new symbols. For T users accessing the MAC simultaneously, 2^T different possible symbols can be transmitted over bit duration (T_b). For example, for T=2 users i.e. U_1 and U_2 $\in$ {-1 1}, the possible symbols are $U_1U_2 \in$ {(-1 -1) (-1 1) (1 -1) (1 1)}. Once the weights (W=[W1 W2])are assigned in a multiplicative manner to the users U_1 and U_2 respectively, then the newly generated multilevel constellation values become S $\in$ {($-W_1 - W_2$) ($-W_1 + W_2$) ($W_1 - W_2$) ($W_1 + W_2$)}.

From Table-1, it can be realized that direct decoding of the original data bits becomes ambiguous for the alphabet or symbol S_k=0 if the trasmission is without any coding. However this ambiguity can be easily avoided using the method of CWC.This ambiguity in the constellation becomes the major source of error in decoding the symbol values ($U_1U_{2...}U_T$) directly. Using complementary weight based coding (CWC), this sort of ambiguous constellation can be easily overcome. Allocating a suitable complementary weight matrix of size (Tx1) can be a solution in decoding the data of T users with satisfactory error performance. The name "complementary" is because of the complementing nature of the weights assigned to each of the T users to make the entire decoding process more error free. The selection of weight values plays an important role in deciding the euclidean distance as well as the required voltage level of transmission for each user.

As shown in Fig. 2, the BPSK modulated data from the i^{th} source, U_i where i=1, 2, . . .T, is encoded by the i^{th} encoder so as to get decoded uniquely at the receiver. The encoder adjusts the amplitude level of each of the T users by multiplying with the predefined weight (W_i). The transmitted signal from every user gets added and finally produce 2^T constellation points uniquely identified. The selection of W plays a very important role in the entire communication process, as it decides for the euclidean distance between any two consecutive constellation points. The ultimate transmitted signal in an additive channel becomes

$$S = W_1 U_1 + W_2 U_2 + \ldots + W_T U_T$$
$$= \sum_{i=1}^{T} W_i U_i \quad (1)$$

Where W_i= weight assigned to i^{th} user and U_i is the BPSK modulated symbol of the i^{th} user i.e. U_1, U2, . . . U_T ϵ { 1, -1} . S= Final summed up signal value of T users. Before proceeding further, the parameters like'd' and $D_{(x)(y)}$ must be defined.

$$d=|W_1-W_2|=|W_2-W_3|=|W_{T-1}-W_T|=\text{weight adjacency} \quad (2)$$

It simply indicates the difference between the adjacent weight values in a complementary weight matrix W= [W_1 W_2 . . . W_T]. Similarly $D_{(n-1)(n)}$ indicates the euclidian distance between any two adjacent values of the resultant constellation generated due to CWC.

$$D_{(n-1)(n)} = |S_{(n-1)} - S_{(n)}| = |S_{(1)} - S_{(2)}| = |S_{(2^T-1)} - S_{(2^T)}| \quad (3)$$

Where n∈ {0, 1,. . .2^T}. Based on the value of the '$D_{(n-1)(n)}$', the type of 2^T-ary constellation (Uniform or Non-uniform) is decided. A constellation with 2^T separate points is uniform, if each point maintains an equal eucidian distance with its adjacent points. Otherwise it is Non-uniform.While selecting the complementary weight matrix (CWM), care should be taken so that the maximum level of resulting constellation or the summed up signal value (S_k) must not exceed ±T i.e. $S_k \leq \pm T$. It will be a way to suppress the need of excess transmitted power appearing in case of most of the techniques involving multi level voltage values carrying information.

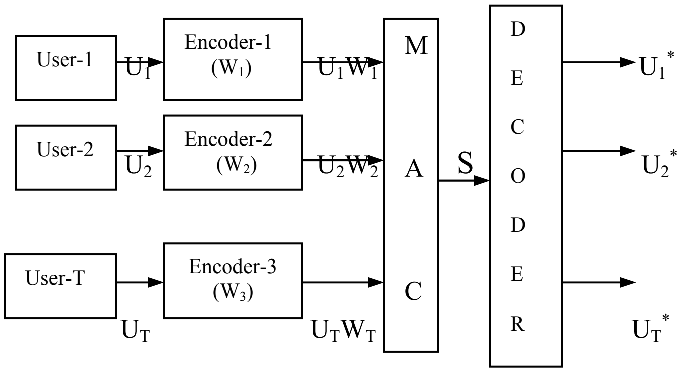

Figure 2. Block diagram of CWC T-User MAC

EXAMPLE-1: (Non Uniform Constellation)
Assuming T=2, for the transmitted symbols U_1=1 and U_2=1

$$W_1 U_1 + W_2 U_2 = 2$$

$$W_2 (1) + W_1 (1) = 2$$

$$W_2 + (W_2 + d) = 2$$

$$W_2 = (2-d)/2$$

(A)

For d= 0.2 W_2= 0.9 and W_1=1.1 => W= [1.1 0.9]

S= [-2 -0.2 0.2 2]

$D_{(0)(1)}$=1.8 $D_{(1)(2)}$=0.4 $D_{(2)(3)}$=1.8

(B)

For d= 0.5 W_2= 0.75 and W_1=1.25 => W= [1.25 0.75]

S=[-2 -0.5 0.5 2]

$D_{(0)(1)}$=1.5 $D_{(1)(2)}$=1 $D_{(2)(3)}$=1.5

From the above two cases, the observation predicts that the constellation gradually gains more uniformity with the increase in the value of'd'.

With the increase of‘d’, the constellation becomes more uniform facilitating better error protection capability during reception. A particular value of d is reached where the constellation becomes completely uniform. At this value of d, the system shows optimality in error performance. This value of‘d’ is called d_{OPT} and the corresponding Weight matrix can be named as $W_{OPT.}$ Proceeding beyond the value of d_{OPT}, the constellation deviates from its uniformity.

Table 2. Constellation Values for a T=2 User system for W= [1.25 0.75]

U_1	U_2	$S= W_1 U_1 + W_2 U_2$
-1	-1	-2
-1	1	-0.5
1	-1	0.5
1	1	2

Table 3. Forbidden/Ambiguous Constellation

U_1	U_2	$S_k= W_1 U_1 + W_2 U_2$
-1	-1	-2
-1	1	0
1	-1	0
1	1	2

In the Table 3, S_k=0 for (U_1 U_2) =(-1 1) or (1 -1) creates ambiguity at the decoder. d=0 => W= [1 1]

3. DECODING TECHNIQUE

The summed up transmitted symbol values can be decoded with suitable decoding method so as to recover the original data of all the T users with no error in noiseless environment and with least error in noisy environment. Simple threshold logic decoder (TLD) with 2^T appropriate threshold levels can be used for the purpose, where simple comparisons can decide for the transmitted symbol. In another approach, the maximum likelihood decoder (MLD) can also be used for the same purpose.

The hard decision (HD) based threshold logic can be implemented to compare and trace the preferred value of the received 2^T–ary constellation over a noisy channel. The following decoding logic can be designed for the hard decision based threshold logic decoder for T=2 user based MAC based on CWC. The threshold logic for T=3, 4. . .N users can be similarly designed as

$$
\begin{aligned}
F(x) &= S_0 \quad \text{if } x < S_0 \quad \text{or} \quad x \geq S_0 + |(S_0-S_1)/2| \\
&= S_1 \quad \text{if } x < S_1 - |(S_0-S_1)/2| \text{ and } x \geq S_1+|(S_1-S_2)/2| \\
&= S_2 \quad \text{if } x < S_1 - |(S_1-S_2)/2| \text{ and } x \geq S_2 + |(S_2-S_3)/2| \\
&= S_3 \quad \text{if } x < S_3 - |(S_2-S_3)/2| \text{ and } x \geq S_3
\end{aligned} \tag{4}
$$

The efficiency of the TLD completely depends on the selection of weight matrix and the extent of uniformity it has. As already discussed, more will be the uniformity; better will be the error protection capability in noisy channel condition. The non-uniformity can lead to the mis-judgment of the original constellation value to its nearest one, hence may lead to lead an erroneous decoding of more than one user at the same time.

4. SIMULATION RESULT

In this section the simulation results of the proposed technique to achieve overloading within limited channel condition has been presented in a comparative manner with respect to the conventional single user BPSK system (T=1). All the simulations have been carried out in MATLAB-R2011 platform. The transmission is assumed to be fully synchronous. Each of the T users data is BPSK modulated. The proposed system has been studied over AWGN channel condition for T=2 and 3 users. The HD-TLD as described above has been preferred for decoding the original information bits transmitted.

Figure 3 manifests the variation of the error performance with respect to the weight adjacency (d). With the increase in the value of d form 0.2 to 0.8, the value of CWM (W) changes from [1.1 0.9] to

[1.4 0.6]. This gradual change in CWM makes the constellation more uniform without any possibility of ambiguous detection. It results in an improved BER performance for d=0.8 as compared to d=0.2. But the improvement in error performance with the value of 'd' changing from 0.6 to 0.8 is less as compared to that for the value of d=0.6 to 0.8. This is because, with d increasing from d=0.2 to 0.4, the change of 0.2 in the value of D_{12} plays a more effective role in avoiding the ambiguity between S_1 and S_2 than that of the d=0.6 to 0.8 case. The change in D_{12} becomes more important due to the two bit change involved during the transition from S_1 to S_2. At higher values of d, the value D_{12} gets sufficient enough to avoid any such of such ambiguity, hence optimality condition is arrived. The single user BPSK system seems to dominate the proposed system for T=2 users with d=0.8 by a SNR gain of ≈ 4dB at a BER of 10^{-3}.

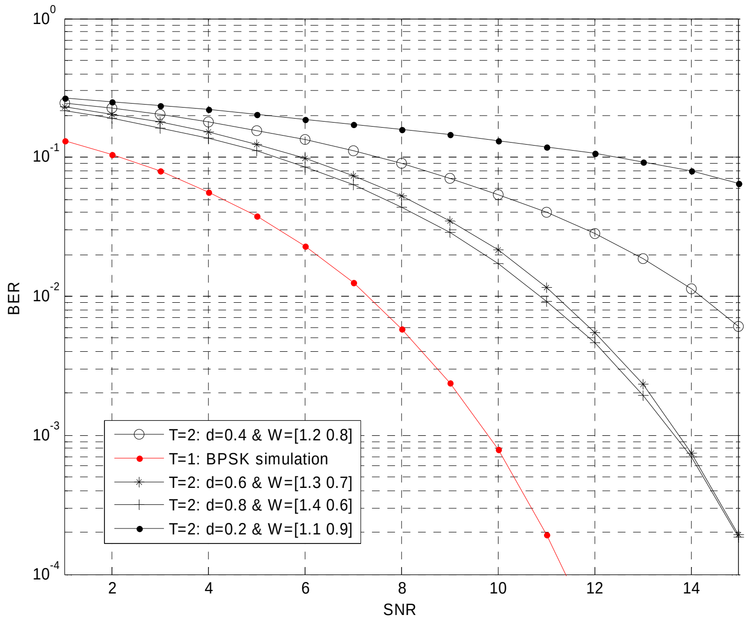

Figure 3. Comparison of BER for different values of d=0.2, 0.4, 0.6, 0.8 for T=2 users

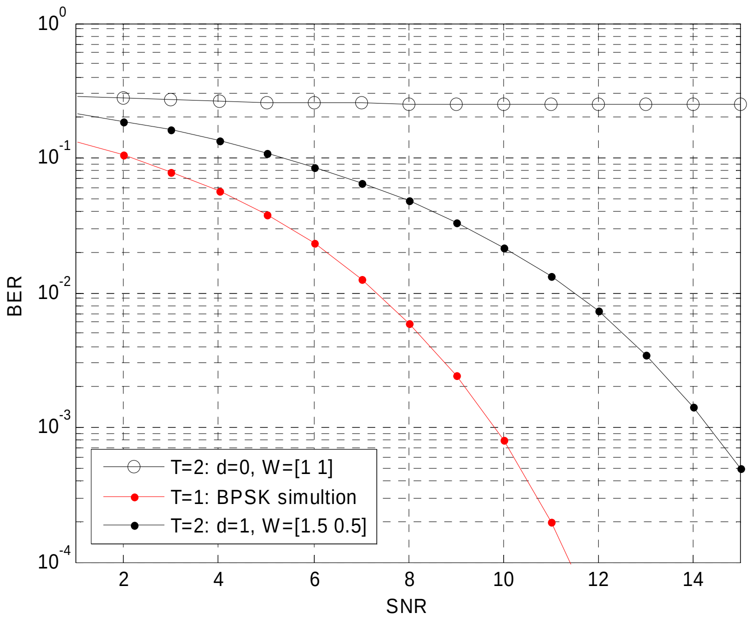

Figure 4. Comparison of BER for different values of d= 0, 1 for T=2 users

Figure 4 presents a comparative analysis of error performance of the system for T=2 users with the minimum and maximum value of d i.e. d_{min}=0 and d_{max}=1. For d=0, the value of CWM becomes W=[1 1] which leads to an ambiguous quaternary constellation of {-2 0 0 2}. It finally lands in the erroneous decoding followed by the deterioration of the BER plot. For d=1, the constellation crosses the optimal value of d (d_{OPT}) e.g. 0.6< d_{OPT} <0.8. So as discussed in the previous sections**,** the error performance though gets upgraded as compared to d=0 but it marginally degrades than that of the d=d_{OPT} case.

In Figure 5, the BER plots for the same value of d=0.8 with difference in the number of users accessing the common channel has been projected. For a fixed value of d, the increase in the total number of users MAC (T) makes the constellation more non uniform even at higher values of d. It results in the degradation in of the error protection capability of the proposed system as shown in Fig 4. For T=3, the BER performance of the system demands more SNR gain as compared to that for T=2 with value of d remaining same.

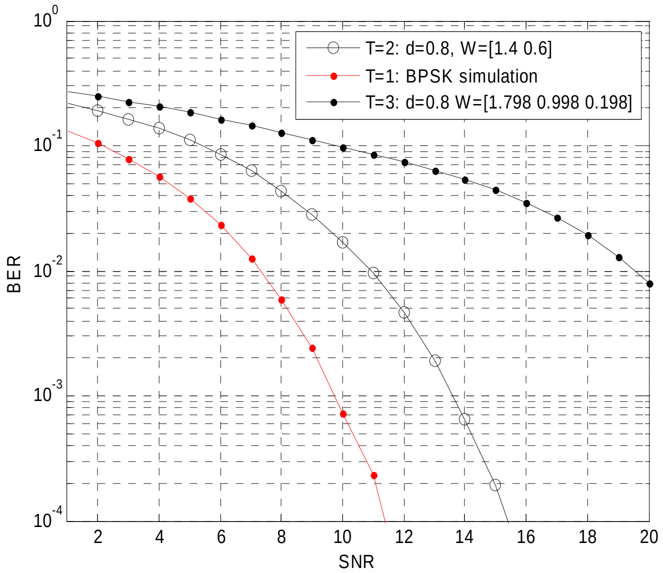

Figure 5. Comparison of BER with different values of T= 2, 3 for same value of d=0.8

5. CONCLUSION

In this paper complementary weight based coding (CWC) as an approach to overload the capacity of MAC has been discussed with a major priority towards the selection of the predefined weights in the CWM. The essence of unifom and non-uniform constellation as a deciding factor towards the error protection capability of proposed technique has also been emphasized. The system was analysed with T=2 and 3 active users operating simultaneously over the same channel. A low complexity HD-TLD with 2^T threshold levels can be used for decoding process. The BER performance with respect to single user BPSK system acts as a reference to judge the error performance of the proposed technique. It was found that, the minimum sacrifice in SNR the users have to make as compared to single user BPSK system is approximately 4 dB to level at a BER of 10^{-3}. But the BER performance seems to degrade marginally with the increase in the number of active users (T), which can further be improvd at the cost of acceptable power loss.

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