Reduced States Multilevel Space Time Coding

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Abstract

There is an increasing demand for higher data rates and higher quality in wireless communications that has motivated the use of multiple antenna elements at both the transmitter and the receiver sides of a wireless link. Space-time coding (STC) deals with the design of good codes of multiple antenna wireless systems.

A new proposed orthogonal code is designed and presented in this paper as an improved design of delay diversity for multilevel space time coding with multiple inputs and multiple outputs. The code is based on using two signals transmitted at different rates in order to remove the problems that appear from different types of fading due to multipath channel and to reduce intersymbol interference (ISI) between the symbols.

The transmitter and the receiver are designed to encode and decode the proposed orthogonal code through the frequency selective and flat fading channels. Time invariant rapidly varying fading channel is included ; that the path gains change for each symbol. The detection is non coherent STC that neither the receiver nor the transmitter knows the channel propagation coefficients. Quasi-static fading channel with coherent STC is also included, that only the receiver has knowledge of the channel through training symbols is available at the beginning of each frame of the receiver. The method gives coding gain, diversity gain as well as the design of the proposed code for three or four transmitting antennas with low complexity.

1 Introduction

Theoretical and experimental studies have shown that the capacity of a wireless channel grows linearly at the minimum number of antennas used at both ends of the channel. The accuracy of the received signal when compared to originally transmitted source information is a broad general measure of the quality of the communication system and the success of the system design [1]. Space-time coding (STC) deals with the design of good codes for multiple antenna wireless systems. Space Time Trellis Code (STTC) is a generalization of delay diversity scheme [2],[3],which can be viewed as a space–time code by defining

$$c_t^1 = c_{t-1}^1$$
$$c_t^2 = c_t^2 \qquad (1)$$

where c_t^1 and c_t^2 are the symbols of the equivalent space–time code at time t and $c_t^1\ c_t^2$ is the output of the encoder at time t.

Space-time trellis codes provide coding gain and also provide full diversity gain, their key advantage over space-time block codes is the provision of coding gain. Their disadvantage is that they are extremely difficult to design and require a computationally intensive encoder and decoder [4].All the space time trellis codes were designed by hand and for fixed rate, diversity advantage, constellation size, and trellis decoding complexity the designer sought to maximize the coding advantage given by the determinant criterion.

In this paper, we propose an efficient code that is suitable for an arbitrary number of transmit antennas with reduced trellis states that reduce the complexity of the encoder.

2 Theory Of Deriving The Proposed Code

A new code is proposed and designed in order to eliminate the effect of multipath signals that cause the transmitted signals from multiple antennas arrive at the destination at different times due to delay. When this delay is larger than the symbol period, it causes intersymbol interference, and hence the decoding of the received signals will not give the original signal.

The basic principle of the new code is that, one of the signals is sent faster than the other at a rate of ½. One of the signals is encoded using a repetition code of length 2 and transmitted on channel one. The other is the original signal delayed by one symbol (rate=

½) is transmitted on channel two. This process leads to insert sample of zero between each two symbols which will separate symbols from each other in order to avoid intersymbol interference (ISI). The resulting code is multilevel space time coding which has the significant advantage that is used for reducing the decoding complexity. At the receiver the antenna combines these two codes together so the original data can be recovered.

At each time t the input to the encoder is one bit of information b^1_t. The input sequence b^1_t is encoded using a repetition code of rate 1/2 giving the output sequence $b^1_t b^1_t$. The other input is encoded using a delay of one symbol period of rate ½ yielding b^1_{t-1}, as shown in. Fig.1.

$$x_1(n)=x(n)+x(n-1)$$
$$x_2(n)=x(n-1)=0.x(n)+x(n-1) \qquad (2)$$

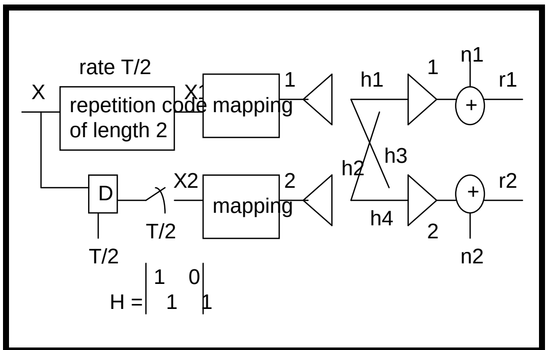


Fig.1: The transmitter of the proposed code.

In matrix form,

$$\begin{bmatrix} x1 \\ x2 \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 0 & 1 \end{bmatrix} . \begin{bmatrix} x(n) \\ x(n-1) \end{bmatrix} \qquad (3)$$

Let $c^1_t = b^1_t$
$c^1_t = 2\, b^1_{t-1} + b^1_{t-1}$ (4)

be elements of the transmitted signals from antennas 1 and 2 at time t is c^1_t and c^2_t respectively. Hence the transmission matrix for this code is given as

$$H = \begin{bmatrix} 1 & 0 \\ 1 & 1 \end{bmatrix} \Rightarrow orthogonal code \qquad (5)$$

The number of row represents the time slot, while the number of column represents the number of transmitting antennas

3 Graphically Derivation The Transmission Matrix H

The transmission matrix H of the proposed code can be derived as follows:

The signals x(n), x1(n) and x2(n) of Fig.1 are shown in Figs.2 (a),(b),and (c). For example, let 4-bits of x(n) are given as:

x(n) = b1,b2,b3,b4 , at t = 0,T,2T,3T the output from a repetition code x1 is given as:

x1(n)= b1,b1,b2,b2,b3,b3,b4,b4 at fs=1/2 ,

and, x2(n) = b1,b2,b3,b4, at fs= 1

where, fs is the sampling rate

x2(n) is given at t = T/2, 3T/2,….etc.

In order to make x2(n) at the same rate of x1(n); x2(n) must be resampling at T/2 as in Fig.1, so adding zeros at n=0,T,2T,3T as in Fig.2(c).

Now the rate of the signals x1(n), x2(n) is T/2 , while the rate of x(n) is T, so the bandwidth of x(n) is BW, where the corresponding bandwidth of x1(n) or x2(n) according to Nyquist rate [5],[6] is 2BW, where BW is the Bandwidth of the baseband signal. Hence the overall bandwidth of the system is increased by 2. The coding rate R of this code is ½ due to sending two bits at two time slots to output one symbol.

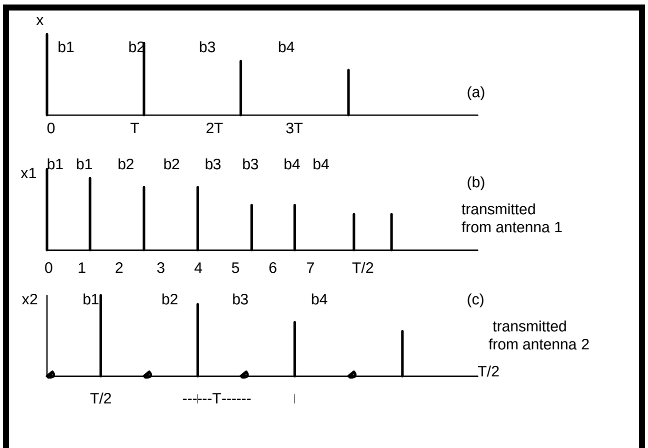


Fig.2: Representing the signals x(n), x1(n), and x2(n) of Fig.1.

4 A Proposed Code For Direct Method

The input data passes through the proposed code directly. Two types of date are used, as binary input (0,1) or mapping to one of the complex modulation signals BPSK or QPSK. Each type of data is used to one type of the channels such as the binary input (0, 1)data is used for rapidly varying fading channel while the modulation type are used for quasi-static fading channel. These types of channels with the corresponding transmitter and receiver are discussed in the following sections.

5 THE PROPOSED CODE FOR RAPIDLY VARYING FADING CHANNEL

The binary input x (0,1) is passed through a proposed code directly, where the trellis diagram for 2 input is given in Fig.3. It is noticed that the state 01 is eliminated due to the new code so it is referred to as reduced states code (RSC). The signals x1 and x2 are transmitted through antennas 1 and 2 respectively without any modulation as shown in Fig.1. At the receiver either one or two antennas may be used. In this method the channel is rapidly varying fading channel and the transmission is non coherent that the channel impulse response CIR is unknown neither at the transmitter nor at the receiver.

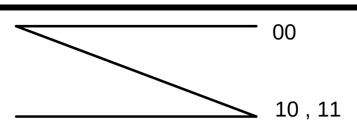


Fig.3: Trellis diagram for the proposed code with binary input and Nr 2.

Hence the channel coefficients h^i_t for i=1,2,3,4 and t=0,1, 2, .., N-1, (N: is the block length) are changed for each symbol . These coefficients associate to the transmit and receive antennas number 1 and 2 are given in Table.1.Where h^i_t, are the channel coefficients associate to the transmit and receive antennas which are modeled as samples of independent complex Gaussian random variable with zero mean and variance 0.5 per dimension, as ([7],[8],[9]). The noise signals n^1_t and n^2_t are added at receiver 1 and 2 respectively at time t. The noise is additive white Gaussian noise

	Rx-1	Rx-2
Time t	r^1_1	r^2_1
Time t+T	r^1_2	r^2_2

AWGN normalized to zero with variance No/2 is 0.5.

Table 1: The definition of channels between the transmitting and the receiving antennas

	Rx-1	Rx-2
Tx-1	h^1_t	h^3_t
Tx- 2	h^2_t	h^4_t

5.1 Digital Transmission Over MIMO Channels

In order to synthesize the transmitted signal , for example let the input data at x be given as d1,d2,d1,d1 where d1 and d2 Є {0,1} . The output from antennas 1 and 2 are given as:

x1 = d1,d1,d2,d2,d1,d1,d1,d1 ------- antenna1

x2 = 0 ,d1,0 ,d2,0 ,d2,0 ,d2 ------- antenna2

For two-transmitting antennas and one receiving antenna number 1 (Rx-1), independent noise samples n^1_t is added at the receiver at each time slot t. The receiving antenna number 1 combines the output signal from transmitting antennas number 1 and 2 (Tx-1)&(Tx-2) [10],[11], hence the received signal r^1_t can be expressed with the aid of eq.(3) as:

$$r^1_t = x^1_t \,.\, h^1_t + x^2_t \,.\, h^2_t + n^1_t \qquad (6)$$

Table 2 defines the received signal at the two receiving antennas for two time slots.

Hence at T=1, x1=d1, x2=0,

and at T=2, x1=x2= d1

Substituting these values in eq.(6) results

At T=1,

$$r^1_1 = d1.h^1_1 + (0)\,.\,h^2_1 + n^1_1 = d1.h^1_1 + n^1_1 \qquad (7)$$

At T=2,

$$r^1_2 = d1.h^1_2 + d1\,.\,h^2_2 + n^1_2$$
$$r^1_2 = d1(h^1_2 + h^2_2) + n^1_2 = d1.h^{1+2}_2 + n^1_2 \qquad (8)$$

Where

h^{1+2}_2 =complex(h^1_1)+complex(h^2_2)=Re +jIm

From eqs. (7) & (8), it is noticed that the values of r^1_1 and r^1_2 at two time slots are the same as using maximum ratio combined in [12], [13]. Due to orthogonality of the proposed code, there is only one symbol d1(or d2) at each symbol period T and the decision is made at the receiver to discriminate the output either 1 or 0.

Table2: The notations for the received signals at the two receiving antennas.

5.2 Decoding For One Receiving Antenna

The received signal r^1_t after adding the noise n^1_t is quantized to '0' and '1' by the comparator to produce the output a1 as shown in Fig.4. A repetition code of length 2 is used at the input, so two values of the output a1's are obtained at two time slots. Let the time T=0,2 ,4,… be called T-even and T=1,3,5 … be called T-odd .A serial to parallel converter is used to obtain a1(T-even) and a1(T-odd) at the same time. These values are combined together by an OR gate in order to guarantee the output ‘1’ and produce the output y1. The input level is increased by a gain, in order to eliminate the noise. So for a low value of gain the output y1 (for one receive antenna) can be obtained without any error.

5.3 Decoding For Two Receiving Antennas

The same procedures that are used for one receiving antenna are repeated for two receiving antennas. The received signal r^2_t after the comparator is a2, and the whole output from the OR gate is y12 as in Fig.4. In order to use the advantage of two antennas combine the two signals y1 and y12 by OR gate to obtain the output y2 .Hence selection diversity [14],[15] is used; to obtain the output ‘1’ from 4 output signals for two receivers.

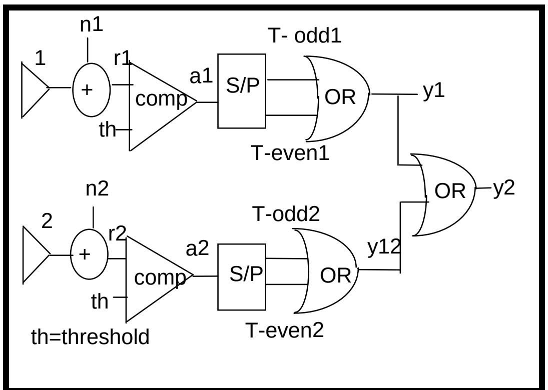


Fig.4:The direct method decoder for binary input.(note : th=0.5 depending on No/2)

5.4 The Proposed Code For MIMO

For 4 transmitting antennas, repeat the matrix H two times where the channel coefficients associate to receiving antenna 1 are h1,h2,h3,h4 and the channel coefficients associate to receiving antenna 2 are h5,h6,h7,h8 as shown in Fig.5. The received signal r^1_t and r^2_t are given as follows:

$r^1_t = x^1_t.h^1_t + x^2_t.h^2_t + x^1_t.h^3_t + x^2_t.h^4_t + n^1_t$	9

$r^2_t = x^1_t.h^5_t + x^2_t.h^6_t + x^1_t.h^7_t + x^2_t.h^8_t + n^2_t$	10

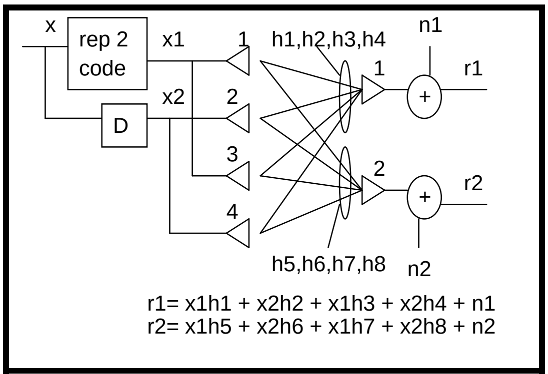


Fig.5: The proposed code for 4 transmitting antennas

For 3-transmitting antennas the antenna number 3 is connected to the first branch x1 in T-odd and connected to the second branch x2 in T-even as in Fig.6 to give r1 and r2 as given below:

$r^1_t = x^1_t.h^1_t + x^2_t.h^2_t + x^1.h^3_t + n^1_t$	11
$r^2_t = x^1_t.h^4_t + x^2_t.h^5_t + x^2_t.h^6_t + n^2_t$	12

So this method can be used for any number of transmitting (Nt) and receiving (Nr) antennas, it is only required that

$Nt \times Nr =$ even	13

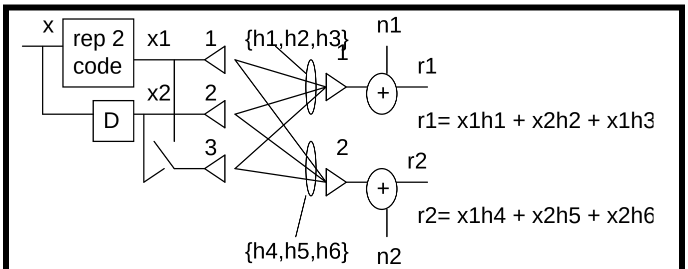


Fig.6: The proposed code for 3 transmitting antennas

6 THE PROPOSED CODE FOR QUASI-STATIC FADING CHANNEL

The input x (0,1,2,3) is put to a proposed code and mapped to one of the complex modulation symbols {0,+j,-1,-j} taken from the QPSK signal constellation ([15],[16])as shown in Fig.1. The channel used is quasi-static fading channel that the channel coefficients h^i_t are constant for one frame and changes from one frame to another as:

$h^i_{t} = h^i_{1}$, for t =0,1,2,..,N-1	13

where N is the frame length.

In order to find the received signals r^1_t for two time slots (T=1 and 2). First it is required to find the trellis diagram for QPSK for the proposed code which is given in Fig.7. It is obvious that the numbers of trellis states are reduced nearly to the half of the conventional STTC .This process reduces the complexity for decoding this code.

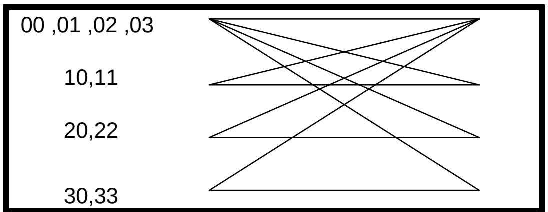


Fig.7: Trellis diagram for the proposed code with QPSK and Nt=2.

Let the channel coefficients associate to the transmit and receive antennas h^1_t,h^2_t,h^3_t and h^4_t are given as in Table 1 .

For example, let the input (+j) , is substituted in eq.(7) for T=1 and in eq.(8) for T= 2 results:

At T=1

$$r^1_1 = (j) \cdot h^1_1 + (0) \cdot h^2_1 + n^1_1$$
$$r^1_1 = |h^1_1| e^{j(\Theta 1+ \pi/2)} + n^1_1 \quad (15)$$

At T=2 ,

$$r^1_2 = (j) \cdot h^1_1 + (j) \cdot h^2_1 + n^1_2$$
$$r^1_2 = (h^1_1 + h^2_1) e^{(j\pi/2)} + n^2_1 \quad (16)$$

From eqs.(15) & (16), it is noticed that the amplitude is not changed but the phase is increased by 0, π/2, π and 3/2π according to the value of the input. Hence when the first four values of the input be used as a training sequence the decision of the output can be made correctly and the effect of noise is small.

For BPSK values the same encoder of Fig.1 is used, where (0,1) the outputs from x1and x2 are mapped to +1, and -1 respectively, and the channel is quasi-static fading channel.

6.1 Minimum Detection For QPSK

The signals a1 and a2 are the angles of the received signals r1 and r2 respectively. These angles are separated to odd and even signals by serial to parallel converter S/P as shown in Fig.8 as od1, ev1, also od2 and ev2 according to the odd and even times respectively. A training input sequences are given at the receiver at the beginning of each frame as x=0,1,2,3, hence the fifth value of od1 is compared to the first four values of od1 given as

$$[d0\ d1\ d2\ d3] = od1_t - [\,od1(0)\ od1(1)\ od1(2)\ od1(3)] \quad (17)$$

The same process is repeated for ev1 compared to the first four values of ev1 given as

$$[e0\ e1 e2\ e3] = ev1_t - [\,ev1(0)\ ev1(1)\ ev1(2)\ ev1(3)] \quad (18)$$

From eqs. (17) & (18) the values of p1 and p2 can be obtained for one receive antenna as follows:

p1 = min | [d0 d1 d2 d3] |,	19
p2 = min | [e0 e1 e2 e3] |,	20

The result is based on whichever is the lowest, the p1 or p2. The mapping in Table 3 is used for decision of the output y1.

Table 3: Mapping method for minimum detection method

if |p1| < |p2| -- p1=	d0	d1	d2	d3
if |p2| < |p1| -- p2=	e0	e1	e2	e3
y1=	0	1	2	3

For two receiving antennas the procedures for od1 and ev1 are repeated for od2 and ev2 and compared to the initial values that produce the values p3, and p4 respectively. The decision is done for the lowest value of p1, p2, p3 and p4 as follows:

1) If min. |[p1,p2,p3, p4] | = p3 or p4
2) Replacing p3 and p4 in Table 3 instead of p1 and p2 and y2 is obtained by mapping operation as in Fig.8.
3) Otherwise i.e.

If min. |[p1,p2,p3, p4] | = p1 or p2 then y2=y1 is obtained from Table 3.

6.2 Minimum Detection For BPSK

The same procedures for QPSK are repeated for BPSK but quantization is done for 2-levels (0,1) rather than 4-levels hence, initial condition x=0,1 at T=0,1 are given at the receiver ,to compare od1 and ev1 to initial conditions [od1(0),od1(1)] and [ev1(0) ev1(1)] respectively as shown in Fig.9. For 1-receiving antenna producing p1and p2 while for 2-receiving antenna producing p3 and p4 respectively in addition to p1 and p2, where p1 and p2 are given as follows:

[d0 d1] = $od1_t$ - [od1(0) od1(1)]	21
[e0 e1] = $ev1_t$ - [ev1(0) ev1(1)]	22
then p1= min |[do d1]|	23

and $p2 = \min |[eo\ \ e1]|$ (24)

Eqs. (23) & (24) are repeated for p3 and p4 . The values S1,S2,S3, and S4 are obtained by mapping operation as in Table 4.

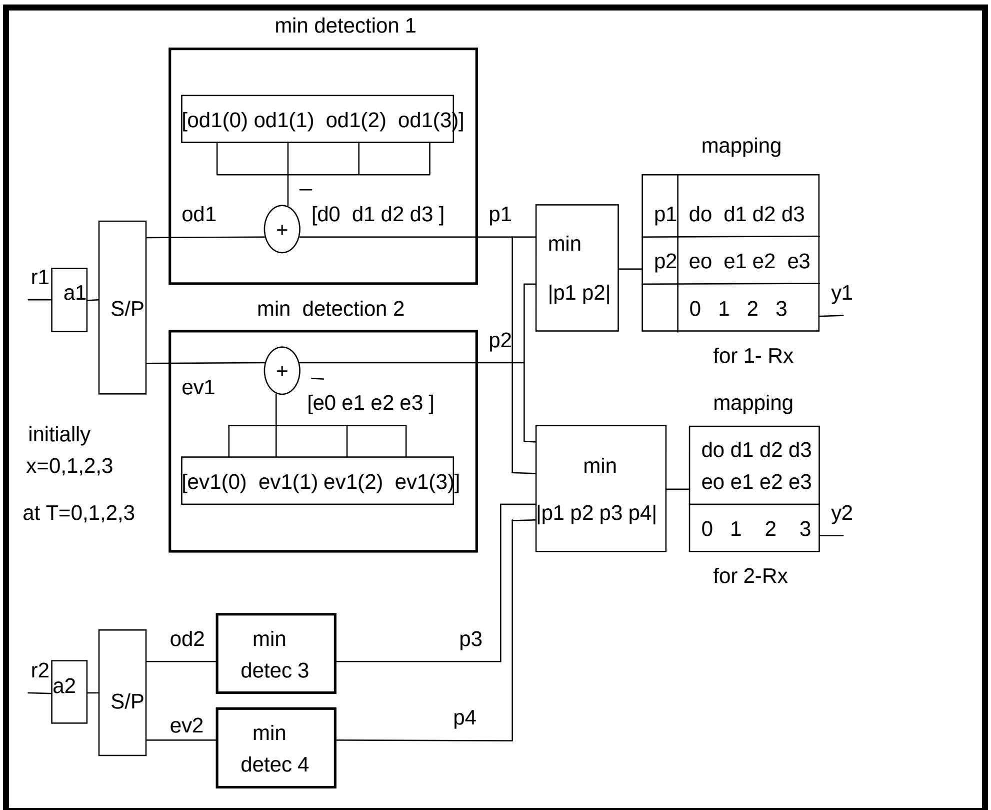


Fig.8: Minimum detection for decoding QPSK input.

Table 4: Mapping table for receiving antennas number 1 and 2.			
For 1-Rx antennas		For 2-Rx antennas	
P1= Min |[d0 d1]|	S1= [0 1]	P3=min |[d0 d1]|	S3= [0 1]
P2= min |[e0 e1]|	S2= [0 1]	P4= min | [e0 e1]|	S4= [0 1]

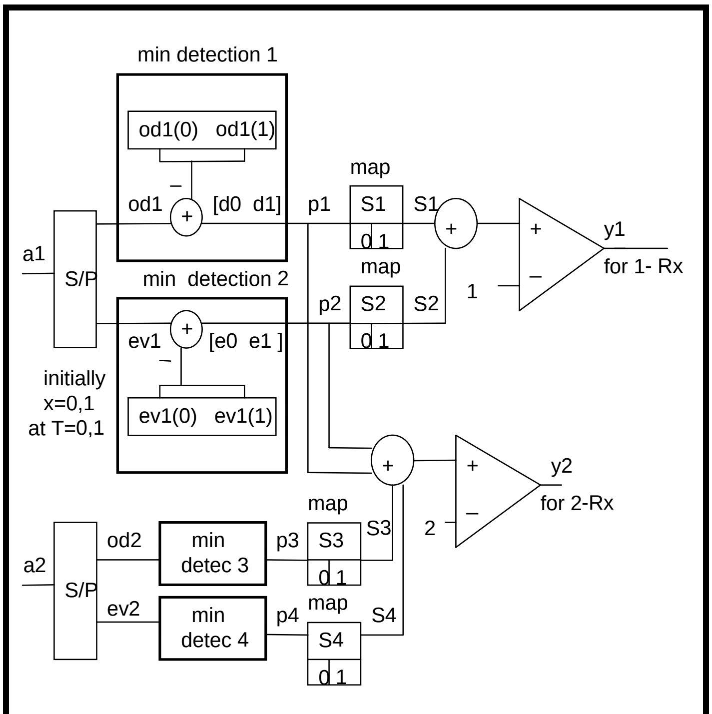


Fig.9: Minimum detection method for decoding BPSK input.

The outputs y1, y2,..,ym for 1,2, and m receiving antennas are obtained as follows:

$$if\ ...\sum_{i=1}^{2} Si\ >=\ 1 \rightarrow\ y1\ =\ 1$$

$$if\ ...\sum_{i=1}^{4} Si\ >=\ 2 \rightarrow\ y2\ =\ 1$$

In general; for m receiving antennas

$$if\ ...\sum_{i=1}^{m} Si >= (m/2) \rightarrow ym = 1$$
$$otherwise\ ..y1, y2,.., ym = 0 \quad (25)$$

7 Simulation Results

The analysis in the previous section provides the improvement of the proposed multilevel space time code over diagonal block space time (DBST) code . Simulation is carried out to evaluate the actual performance gain in practical Eb/No(dB) region. Simulation is performed with two different channels in the time domain and the results are compared with (DBST) code[16], because this reference used STTC and gave the best results of all the existing papers that are used STTC. But the reference designed the code by hand due to the complexity of designing STTC is still exist.

7.1 Rapidly Varying Fading Channel

This method is a noncoherent detection STC and the results are taken for binary input case and for different number of transmitting antennas Nt=2,3, and 4 and for different number of receiving antennas Nr= 1,2,3 and 4 as in Fig 10. From the graph it is better to increase the number of transmitting antennas Nt rather than the number of receiving antennas Nr. The result is better than diagonal block space time code such that for BER=10^{-4} coding advantage is 13dB for 3Tx-2Rx antennas and 1dB when comparing 3Tx-1Rx in diagonal method with 2Tx-1Rx for the proposed method at BER=1×10^{-3}.

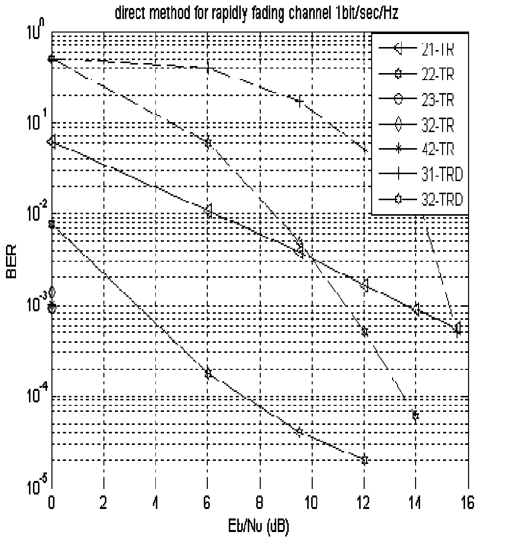
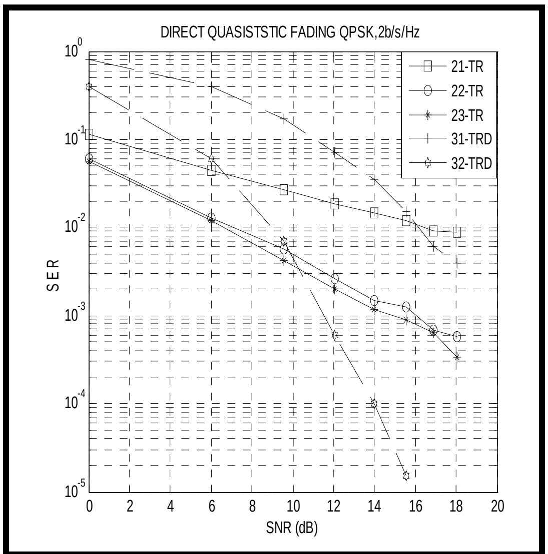


Fig.10: BER performance of binary code with Nt=2 ,3,4 and Nr=1,2,3 over a rapid fading channel

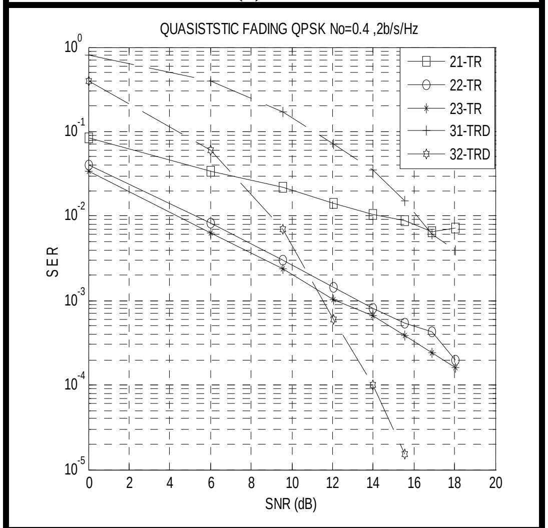
7.2 Quasi-Static Fading Channel

The graph in Fig.11(a) for 2Tx-3Rx of the proposed method is nearly equal to 2Tx-2Rx when the input x (0,1,2,3) is mapped to QPSK complex values. The result is better than 3Tx-1Rx diagonal block space time DBST code but is worse than 3Tx-2Rx DBSTC method. This is due to the effect of noise .When the noise is reduced to variance No=0.4 gives the graph shown in Fig.11 (b). Hence for No=0.5, BER=1×10^{-3} at 16 dB for 2Tx-2Rx while for 3Tx-1Rx DBST code does not reach this value of BER. While for No=0.4, BER=2×10^{-4} at 18dB for 2Tx-2Rx while for 3Tx-2Rx DBST code BER=1×10^{-4} at 14 dB.

When the input x (0,1) is mapped to BPSK real (+1,-1) or complex (+j,-j) values the results are as shown in Fig.12 (a) & (b) . For No=0.5 , BER=2×10^{-4} at 15.5 dB for 2Tx-4 Rx while for DBST code BER=2×10^{-4} at 13 dB for 3Tx-2Rx. While for No=0.4, BER=1×10^{-4} at 14 dB for both methods. Hence it is found that there is a different choice to obtain BER=110^{-4} either using 2Tx-4Rx antennas or using 3Tx-2Rx depends on the required application. The properties of the proposed method for different types of channels are given in Table 5.

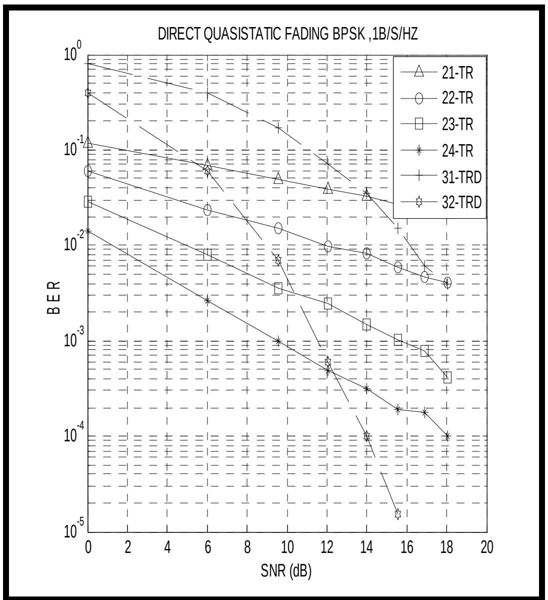


(a) No=0.5

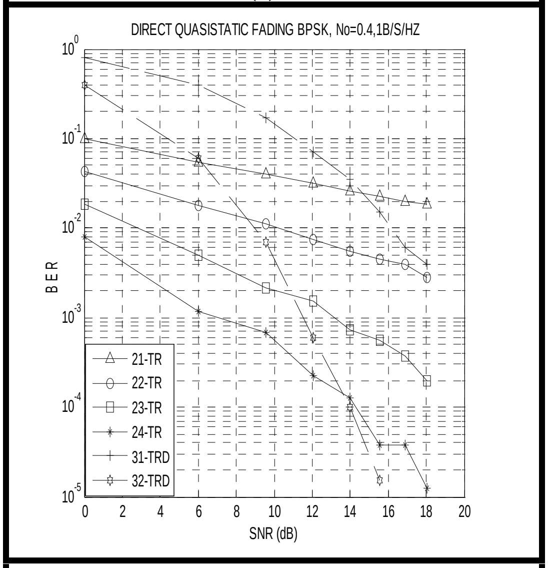


(b) No=0.4

Fig.11: FER performance of QPSK code with Nt=2 and Nr=1, 2, and 3 over a quasi-static fading channel, with variance No (a) 0.5(b) 0.4.



(a) No=0.5



(b) No=0.4

Fig.12: FER performance of BPSK code with Nt=2 and Nr=1,2,3, and 4 over a quasi-static fading channel, with variance No(a)0.5(b)0.4.

8 Conclusions

The properties of the proposed method for different types of channels are given as follows:

1) Using a multilevel space time code for designing the reduced states code (RSC) simplifies the decoding process.
2) The proposed RSC code gives coding advantage in addition to diversity advantage the same as the space time trellis code.
3) Code rate k/n = 1/2
4) For rapid varying channel the BER depends on increasing the number of transmitters rather than the number of

receivers and it is a noncoherent method which does not require channel estimation.

5) For quasistatic fading channel the BER depends on increasing the number of receivers rather than the number of transmitters.
6) The bandwidth in all these methods is twice the bandwidth of the original signal.
7) The complexity is very low, and can be designed for any number of transmitters and receivers.

9 References

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