ISSN 2229-5518

A Robust Algorithm to Decode Trellis Coded Modulation in DMR Systems

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Abstract— Digital Mobile Radio (DMR) is a digital radio standard which was developed by the European Telecommunication Standard Institute (ETSI) for the Professional Mobile Radio (PMR) users. DMR uses state of the art Forward Error Correction methods for reliable transmission and reception. Trellis Coded Modulation (TCM) is a bandwidth efficient modulation. In this paper, we propose a competent and fast decoding method for a Rate 3/4 Trellis Code used in DMR systems. TCM coding is based on the key factor of signal-set partitioning. The trellis encoder is implemented as a Finite State Machine (FSM). The decoding is based on Maximum Likelihood (ML) detection employing Finite State Table of the coder and also the constellation mapper. The decoding algorithm is simulated using MATLAB on an Additive White Gaussian Noise (AWGN) channel. The simulation results shows a coding gain of 2dB and the algorithm is able to correct up to two consecutive bit errors.

Index Terms --Wireless Communication, Digital Mobile Radio, Trellis Coded Modulation, Channel coding, Bandwidth Conservation, Coding Gain, Bit Error Rate

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1 INTRODUCTION

Digital Mobile Radio (DMR) is a digital radio standard specified for professional mobile radio (PMR) users developed by the European Telecommunications Standards Institute (ETSI), and first ratified in 2005. DMR provides voice, data and other supplementary services. DMR [1] uses state of the art Forward Error Correction methods for reliable transmission and reception.

Trellis coded Modulation (TCM) was invented by Gottfried Ungerboeck [2] while working for IBM. In 1976, he first described it in a conference paper. The coding scheme got widespread recognition and it is used in almost all communication systems. TCM is a bandwidth efficient modulation. The bandwidth conservation is carried out by doubling the constellation points of the signal. This change does not affect the symbol rate and it remains constant.

TCM is a combination of redundant non-binary modulation and finite state encoder [3]. This controls the selection of modulation signals, which generate coded signal sequences. Once aired, the signals have to face different channel conditions which add noise to the information [4]. We use a soft-decision maximum likelihood decoder at the receiver to decode the noisy signals. Comparing with the conventional or uncoded modulation TCM could improve the coding gain by 2 to 6 dB. This gain is no way at the cost of bandwidth or information rate. In this paper, we present an implementation of Trellis coding in DMR systems. The algorithm utilizes the Finite State Table of the coder and also the constellation mapper.

In Section II, the background of trellis coding is discussed. The proposed algorithm for the trellis implementation in DMR is discussed in Section III. In Section IV the simulation setup and the BER plot are presented.

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2 TRELLIS CODING

Basically the scheme is a convolutional code and the coding rate is n/ (n+1). Trellis codes' key feature is anchored on the concept of signal-set partitioning. In the signal space, that create redundancy for coding [4].

The concept of tree or trellis coding is used in TCM and that is how the name, Trellis Coded Modulation. Not all bits are encoded by the convolutional coder. The general structure is as shown in Figure 1.

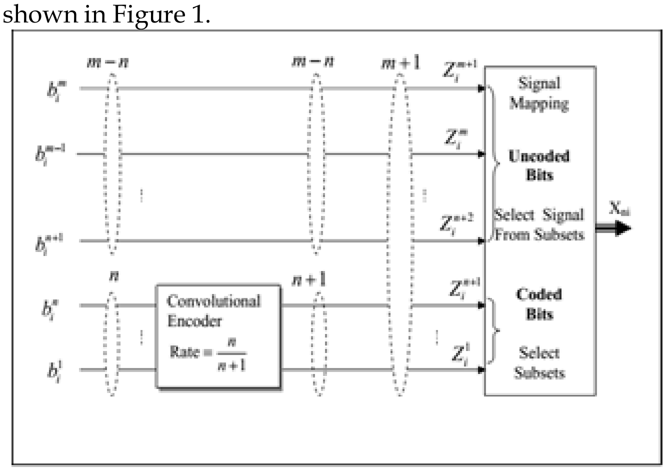

Fig. 1. General Structure of TCM encoder

2.1 Distance Measure

In a 2-dimensional signal space as shown in Figure 2, the two orthonormal basis functions defines the two dimensions. These orthonormal basis functions are corresponding to the information symbols. When narrow band modulated signals

International Journal of Scientific & Engineering Research, Volume 7, Issue 4, April-2016

ISSN 2229-5518

are considered, the dimensions can be interpreted as real and imaginary axes. As the locations of the constellation points are separate, they are distinguishable. Various possible subsets are shown in figure 2.

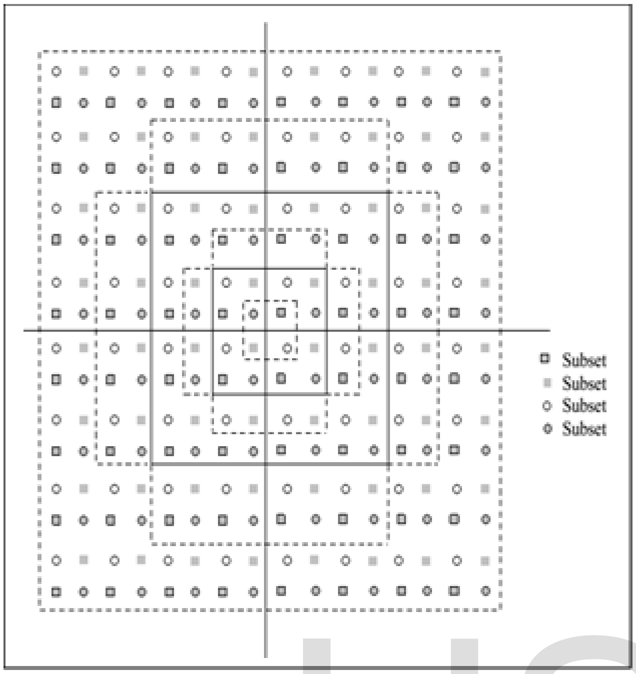

Fig.2. 2D Signal constellations of TCM

The squared Euclidian Distance [11] is the distance between all points of a constellation and the minimum squared Euclidian distance is usually the distance between any two adjacent points.

2.2 Set Partitioning

TCM coding is based on the key factor of signal-set partitioning [12]. The greatest advantage of this set partitioning is that the minimum Euclidean distance of a TCM scheme is maximized. Figure 3 shows the basic concept of set partitioning for a particular signal constellation. The signal constellation consists of 16 signal points and four information bits represent each point. This set is again divided into smaller sets by taking in account of larger values of the minimum distance between the sets. This is continued till the smallest signal constellations are obtained. In the Figure 3, these are represented as D0, D1 ... D7. Here all the signal points are equally probable. While set- partitioning, there are some basic rules to be followed. Parallel transitions are assigned to the members of the same partition and members of the next larger partition are assigned to adjacent transitions.

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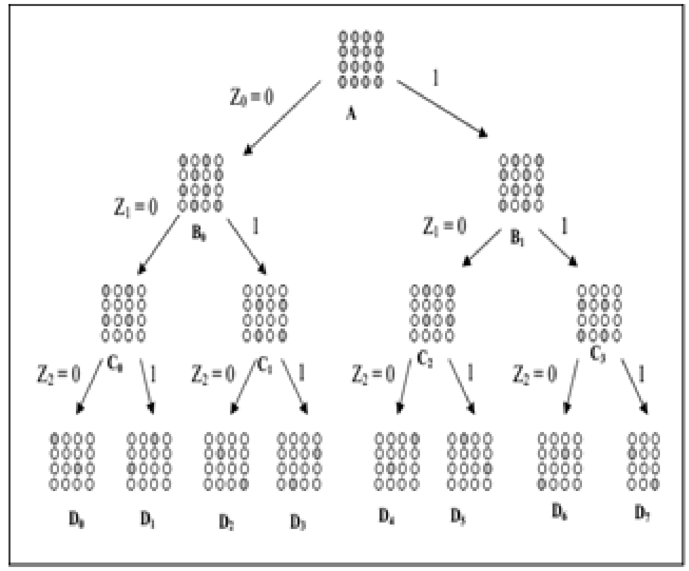

Fig. 3. Concept of set partitioning

3 CODING ALGORITHM

In DMR, rate ¾ trellis code is used and this coding scheme is used to encode the 'Rate ¾ Data Continuation' and the 'Rate ¾ Last Data Block' fields. Data blocks for both confirmed and unconfirmed data packets use this encoding.

3.1 Encoder

An overview of the encoding process is as shown in Figure 4. The input to the rate ¾ encoder is 144 bits (n = 18 octets). The data octets are serialized in the same way, but they are separated into 48 tribits (k = 3) for the encoder. In the encoding process [1], the encoder first serializes a sequence of octets. It is done from left to right. Then each block is subdivided into a serial stream of tri-bits, as shown in the Figure 3. The Most Significant Bit (MSB) is at the left and the Least Significant Bit (LSB) is at the right of each tri-bit. So, we can represent each tribit using octal numbers from 0 to 7. The stream of tribits is now ready for encoding and is fed to the trellis encoder, with tribit 0 at the starting position and ending with tribit m-1.

ISSN 2229-5518

The code word sizes of the Rate ¾ Trellis code is as shown in the Table 1.

TABLE 1

TRELLIS CODE WORD SIZES

Rate 3/4	
Input Size	48 tribits
Output Size	98 dibits
(n, k)	(196, 144)

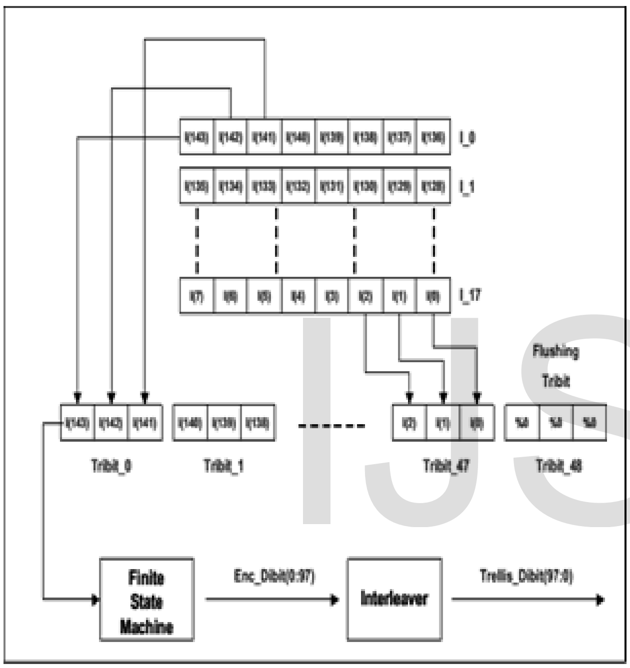

Fig.4. Rate ¾ Trellis encoder overview

The trellis encoder is implemented as a Finite State Machine (FSM). In order to flush out the final state, a 0002 tribit is appended at the end of the stream. The tribits are appended with a flushing dibit tribit (000), to round the number of tribits to the final m = 49, and then passed through atrellis finite state machine. The output of the trellis fine state machine is a sequence of 49 constellation points or 98 dibits (196 bits), where each constellation point represents a pair of dibits. The encoder receives m tribits on the input side. It outputs 2m dibits. These output dibits are mapped to -1, -3, +1, +3 amplitudes and then interleaved. After that, 4-FSK modulation is done.

The encoding process is shown in Figure 5. The encoder is an 8-state Finite State Machine (FSM) for the code rate ¾, with an initial state of zero. The FSM used in this particular implementation has the special property of having the current input as the next state. For each tribit input, there is a corresponding output constellation point which is represented as a dibit pair.

The state transition is shown in table II. The output of the state transition table is one of 16 constellation points. The Constellation to dibit pair mapping is shown in table III.

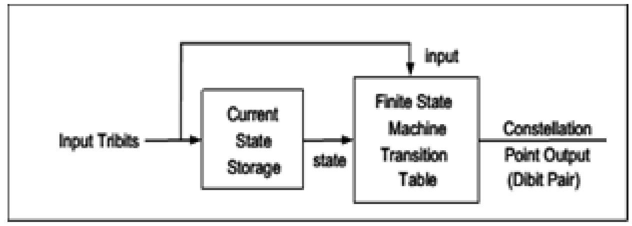

Fig.5. Trellis encoder block diagram

TABLE 2

STATE TRANSITION TABLE

		Input Tribit							
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**
FSM State	**0**	0	8	4	12	2	10	6	14
	1	4	12	2	10	6	14	0	8
	2	1	9	5	13	3	11	7	15
	3	5	13	3	11	7	15	1	9
	4	3	11	7	15	1	9	5	13
	5	7	15	1	9	5	13	3	11
	6	2	10	6	14	0	8	4	12
	7	6	14	0	8	4	12	2	10

TABLE 3

CONSTELLATION MAPPING

Constellation Point	Dibit 0	Dibit 1
0	+1	-1
1	-1	-1
2	+3	-3
3	-3	-3
4	-3	-1
5	+3	-1
6	-1	-3
7	+1	-3
8	-3	+3
9	+3	+3
10	-1	+1
11	+1	+1
12	+1	+3
13	-1	+3
14	+3	+1
15	-3	+1

ISSN 2229-5518

Interleaving is done for data blocks for the code rate ¾. The purpose of the interleaver is to spread burst errors due to Rayleigh fading over the 98 dibit block. In the interleaver, the dibit array is rearranged to form another dibit array according to the interleave table shown in table IV.

TABLE 4
INTERLEAVING SCHEDULE

Enc Index	Input Index	Enc Index	Input Index	Enc Index	Input Index	Enc Index	Input Index
0	0	26	2	50	4	74	6
1	1	27	3	51	5	75	7
2	8	28	10	52	12	76	14
3	9	29	11	53	13	77	15
4	16	30	18	54	20	78	22
5	17	31	19	55	21	79	23
6	24	32	26	56	28	80	30
7	25	33	27	57	29	81	31
8	32	34	34	58	36	82	38
9	33	35	35	59	37	83	39
10	40	36	42	60	44	84	46
11	41	37	43	61	45	85	47
12	48	38	50	62	52	86	54
13	49	39	51	63	53	87	55
14	56	40	58	64	60	88	62
15	57	41	59	65	61	89	63
16	64	42	66	66	68	90	70
17	65	43	67	67	69	91	71
18	72	44	74	68	76	92	78
19	73	45	75	69	77	93	79
20	80	46	82	70	84	94	86
21	81	47	83	71	85	95	87
22	88	48	90	72	92	96	94
23	89	49	91	73	93	97	95
24	96						
25	97						

3.2 Decoder

The decoding is a reverse process of the encoding. The input to the decoder is a sequence of 98 dibits (196 bits) received from the inverse interleaving block. The decoding is based on maximum likelihood detection. The Trellis decoder at first deinterleaves the demodulated dibits stream. The next step is to quantize the deinterleaved output to a range between -30(-3V) to +30(+3V) with a step size = 0.1V. Then the important step in decoding is to trace the path.

In the encoding process, the initial sate and final state is 000. So, the decoding procedure starts from the 0 state. Not all states are possible for a given state. The state transition table shown in the table II is used to trace the possible paths of the received stream of data. If there is any bit error, the next state got while tracing will not be a possible one as per the transition table.

At this stage, we calculate the Euclidian distance between the current state and all the possible states. Now the path with the smallest distance is taken as the survivor path and the decoding is continued. Finally the states of the survivor path give the decoded output. It will be in tribit form and is regrouped to form bits. The method can correct up to two consecutive bit errors.

4 SIMULATION AND RESULTS

The BER performance of the rate ¾ trellis codec is analyzed.

4.1 Simulation Setup

Simulation is done using MATLAB 7.10. Random bits are generated and are encoded using the encoding method detailed in the section III. The channel we have used for the simulation is Additive White Gaussian Noise (AWGN) channel. The noisy received data stream is fed to the receiver module and it decodes as per the algorithm mentioned in the section III.

4.2 Simulation Results

The BER plot that we got after the simulation is as shown in the Figure 6

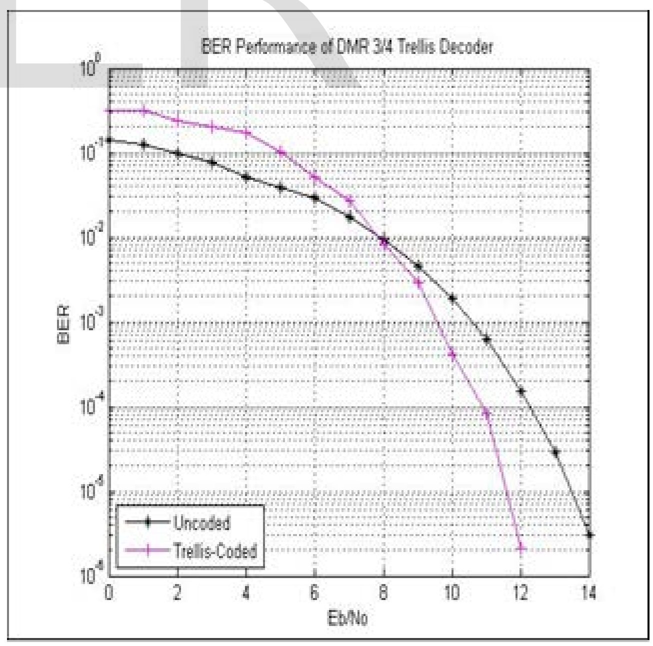

Fig 6. BER Performance in AWGN channel

The simulation result shows a coding gain of around 2dB using this method, even though the method is not effective when the signal power is too low.

5 Conclusion

The method proposed is an effective and fast decoding algorithm for rate ¾ trellis code. An approximate 2 dB coding gain, under AWGN channel conditions, is realized using this method. The algorithm is capable of correcting up to two consecutive bit errors.

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