Space Time coding for data transmission over power line channel

R L Itagi, Dr. K P Vittal and Dr. U Sripati

Abstract-- **Power line channel for data transmission using digital modulation is considered to be used for sub station automation. Because of time-varying nonwhite noise being present on power line, power line channel can be modeled as multipath channel. Middleton Class-A noise model is used to simulate impulse noise on power line. The concept of space and time diversity given by Almouti, known as space time coding is used for data transmission over power line channel. Space time coding requires channel estimation, which is performed using pilot symbol data. Combination of BCH code concatenated with Convolution Turbo code employed as error correcting code ensures proper data recovery under severe channel disturbances.**

***Index Terms*--Turbo code, BCH code, Class A noise, space time coding.**

I. Introduction

The digital modulation schemes employed for data transmission using power lines take the turn from FSK (Frequency Shift Keying), PSK(Phase Shift Keying) to orthogonal frequency division multiplexing.

Applications of power line communication are classified as for broadband communication over residential power line, home automation, home surveillance systems and substation automation. A substation is said to be automated when it employs intelligent electrical/electronic devices for supervisory and control actions of the substation.

Power lines when transmitting digital data using a high frequency carrier signal, act like antenna and radiate power, which is termed as EMI (Electro Magnetic Interference). Hence reduction of carrier power is the need and is open to research.

The merit of no extra cost as the lines are already laid makes one to think in the direction of finding a scheme that obeys the norms of EMI [1].

Power line channel being modeled as multipath model [1], [2] and [3], space time coding along with an efficient error correcting code can be used to achieve signal power reduction. Data communication over power lines, for the purpose of substation automation is explained in this paper, with space time coding employing phase shift keying modulation preceded by Convolutional turbo code.

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II. Space Time Coding

Multiple-input and multiple-output, or MIMO, is the use of multiple antennas at both the transmitter and receiver to improve performance of communication in a multipath channel. A multipath channel is the communication cannel in which the signal received is the superposition of the multiple signals received from different paths from the transmitter [5].

Power line channel is a multipath channel wherein the reflecting paths on the line exist due to impedance mismatch of various loads applied at varying time instants and causing time variant impulse noise. As a result of this, the time and frequency dependent transfer function of the power line channel disturbs the recovery of data at the receiving end.

Use of two transmit one receive antenna system employing Almouti's space time coding [4] can be applied to power line communication, as the scheme ensures the signal availability at the receiver. Signal availability is due to fading, the property of the multipath power line channel. Fading is the property of the multipath channel and is nothing but signal variations from minimum in one path to maximum in another path.

Table 1 explains the scheme of space time coding for communication over power line channel. Two symbols are transmitted in two symbol intervals but repeated alternatively on two transmit antennas.

The detailed mathematical support to design the receiving scheme is explained in [4].

The signal recovery at the receiver requires the channel estimation.

TABLE I
ALMOUTI SCHEME OF SIGNAL TRANSMISSION

	Time instant 1	Time instant 2
Transmitter point 1	symbol 1	-conj(symbol 2)
Transmitter point 2	symbol 2	Conj(symbol 1)

Channel estimation is nothing but predicting the values of transfer functions of the power line (communication channel) for the two received paths.

Channel estimation achieved in this paper is proposed by adding dummy (pilot) symbols alternate along with the data symbols. Transfer function of the channel for the duration of known dummy data is computed from the received output. The same value of transfer function is used as estimate of the channel state during actual data symbol to estimate the actual data.

The data symbols are further recovered with the help of equations (2.1) and (2.2) transfer functions for the present instant being replaced by transfer functions predicted in the previous instant.

soe=conj (Ho)*r (1, 1)+H1*conj(r(1,1)) (2.1)

s1e=conj(H1)*r(1,1)-Ho*conj(r(1,1)) (2.2)

III. TURBO CODES

A. Introduction to Turbo codes

The invention of Turbo codes in the early 1990's and their first public presentation in May 1993, by Berrou, Alain Glavieux, and Thitimajashima, titled "Near Shannon Limit Error-Correcting coding and Decoding: Turbo Codes", at the IEEE International Conference on Communications (ICC) at Geneva, showed the pertinence of this approach for communications. This revolutionary concept resulted into a new code construction from well known components was what was needed to usher in a revolution [9]. The Turbo encoder and decoder for four state Parallel Concatenated Convolutional Code (PCCC) is used in this paper. The sub class of PCCC which is Recursive Systematic Convolutional Code (RSC) is used for the purpose.

B. Turbo Encoder

The recursive systematic convolutional (RSC) encoder [8] is obtained from the non recursive nonsystematic (conventional) convolutional encoder by feeding back one of its encoded outputs to its input. Fig. 1 shows the RSC encoder.

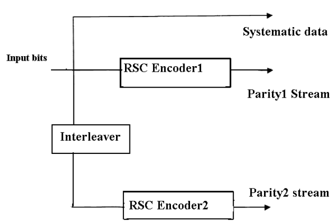

Fig. 1 Turbo Encoder Block Diagram

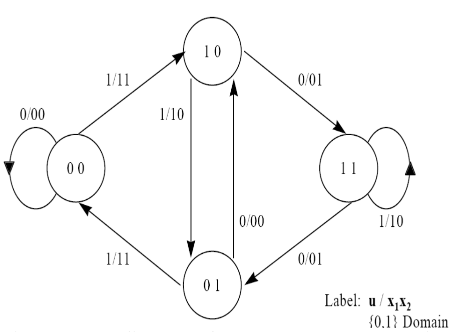

Fig. 2 State diagram of two memory RSC encoder

The generator matrix for two memory RSC encoder is given by G = [1 $(1+D^2)/(1+D+D^2)$]. Fig. 2 shows the state diagram of the RSC component encoder. The numbers of states generated are four.

C. Turbo Decoding And Bcjr Algorithm

In 1974 Bahl, Cocke, Jelinek and Raviv introduced MAP decoder called as BCJR algorithm [8], [9], which can be applied to any linear code, block code or convolutional code. The algorithm calculates the a posteriori L values called the APP L values, of each information bit. The BCJR algorithm works on a trellis representing the finite-state machine and its complexity is proportional to the number of trellis states.

In the algorithm for turbo decoding the first computational block is the branch metric computation. The branch metrics are computed based on the knowledge of input and output associated with the branch during the transition from one state to another.

The branch metric is calculated differently for message and tail bits.

$$\gamma(s',s) = u_l L(u_l)/2 + L_c r_l v_l/2, l = 0,1,..,k-1.$$
$$\gamma(s',s) = L_c r_l v_l/2, l = k, k+1,.....,k-1. \qquad (3.1)$$

The forward metric is the next computation in the algorithm, which represents the probability of a state at time k, given the probabilities of states at previous time instants. Forward metric is computed as.

$$\alpha_{l+1}(s) = \max\,[\gamma_l(s', s) + \alpha_l(s')], l=0, 1,\ldots K-1. \qquad (3.2)$$

The backward state probability being in each state of the trellis at each time k, given the knowledge of all the future received symbols, is recursively calculated and stored. Backward metric is found as

$$\beta_l(s') = \max\,[\gamma_l(s', s) + \beta_{l+1}(s)], l=k-1, k-2,\ldots 0 \qquad (3.3)$$

Log likelihood ratio is the output of the turbo decoder. This output for each symbol at time k is calculated as

$$L(u)=\max_{(s', s)\in 1,1}[\beta_{l+1}(s) + \gamma_l(s', s+\alpha_l(s') + \alpha_l(s')]$$
$$-\max_{(s', s)\in 1,0}[\beta_{l+1}(s) + \gamma_l(s', s+\alpha_l(s') + \alpha_l(s')] \qquad (3.4)$$

The hard decision is then computed using (5).

$$u_l = +1, L(u_l) > 0$$
$$u_l = -1, L(u_l) < 0, l = 0,1,\ldots.k-1. \qquad (3.5)$$

The calculation can be simplified by using max-log-map algorithm which just finds the maximum of two values. Thus

$\max^*(x, y) = \ln(e^x + e^y) \approx \max(x, y)$

Max-log-map replaces max* by max. Though it is less accurate when compared to log map algorithm [8], but it is simpler and faster to implement.

Log likelihood ratios are modified to suit to impulsive pdf of power line [10].

IV. POWER LINE CHANNEL CHARACTERISTICS AND NOISE TYPES

Power line channel suffers from Impedance mismatches [1] and impulse noise [1], [2], [3] and [6]. Impedance mismatch results in frequency distortion [1], [6], and [7]. Frequency distortion is explained by frequency domain transfer function of the channel [1], given by (5.1). Channel Model for causing reflections on power line can be treated equivalent to channel model for a fading channel [3], [6], and [7]. Multipath channel model simulation explained by Rappaport [5] is used to simulate the same.

$$H(f) = \sum_{i=1}^{N} g_i \cdot A(f, d_i) \cdot e^{-j2\Pi f\tau_i} \quad (4.1)$$

$$H(f) = \sum_{i=1}^{N} g_i \cdot e^{-(a_0 + a_1 \cdot f^k) \cdot d_i} \cdot e^{-j2\Pi f\tau_i} \quad (4.2)$$

The reference [11] suggests that Middleton Class A Model referred to impulsive noise follows pdf given by (4.3), where σ_m^2 is noise variance.

$$f(x) = \frac{A^m}{m!} e^{(-A)} \left[\frac{1}{\sqrt{2\Pi \sigma_m^2}} \right] \cdot e^{\left(\frac{-x^2}{2\sigma_m^2}\right)} \quad (4.3)$$

Equation (4.3) is a weighted sum of Gaussian distributions [12].

with $\sigma_m^2 = \sigma^2 (m/A+T)/(1+T)$, index, $T = \sigma_G^2 / \sigma_{GI}^2$ is the GIR (Gaussian-to-Impulsive noise power Ratio).

$\sigma^2 = \sigma_G^2 + \sigma_{GI}^2$ is the total noise power. The noise x followed by (4.3) always includes the background Gaussian noise with power σ_G^2 [11], [12].

V. Results and Conclusion

Power line channel is simulated using (4.2) using N=4 and distances (d_i) of multipath assumed between 100-200meters. BCH (Bose Chaudhuari Hocquenghem) code with n=127 and k= 22 is used along with Turbo convolutional code as error correcting code. Turbo encoded data is PSK modulated and passed through channel using space time coding scheme as per table 1. Matlab 7.4 is used to test the simulation results.

Fig.3 shows the variation of probability of bit error with signal to noise ratio (SNR) in decibels (dB). Results were verified for data length of 10^3 bits to 10^6 bits. Error is observed to reach zero approximately at about 15 dB for outer BCH code. Use of Turbo code is verified to be essential to provide consistent results under worst channel conditions.

It is concluded with the results that dummy data symbols serve the purpose of channel estimation and space time coding is found to assist turbo code to bring down the value of P_e, to further assist BCH code to remove errors to the order of P_e of 10^{-5}.

The scope for further work could be to test the results using other type of power line channel model such as ABCD parameters. Modulation scheme other than PSK such as M-ary QAM or M-ary PSK or FSK can be tested to improve the bit transmission capacity.

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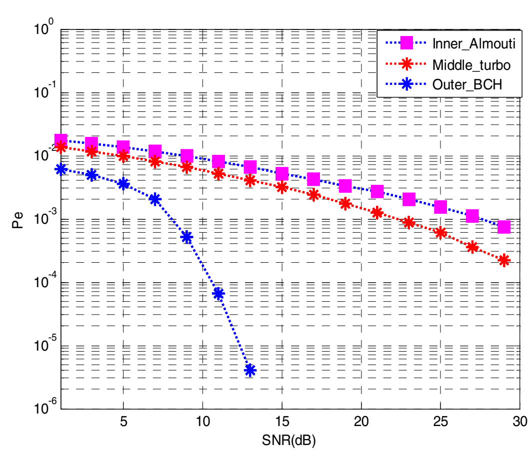

Fig.3 Pe vs. SNR graph

7. BIOGRAPHIES

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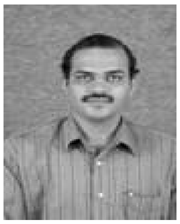

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