

CONCATENATION OF BCH CODE WITH SPACE TIME CODE A LOW SNR APPROACH FOR COMMUNICATION OVER POWER LINES FOR SUBSTATION AUTOMATION

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ABSTRACT

A study of power line as communication medium for narrowband application is performed in the perspective of space time coding. The spatial diversity available in the naturally decoupled phases of the power line can be exploited for using power line as communication medium for narrowband application just as in case of fading channel of a wireless communication. In this paper, a study is performed to test the transmission of digital data using simulated power line. Time and frequency dependent transfer function of the power line is varied instantaneously during data transmission, which is a characteristic of the power line. Impulsive disturbance on the power line is modeled using Middleton class-A noise. BCH code is used as outer code to reduce the SNR requirement. Concatenation of BCH code with space time code is found to reduce the SNR requirement to have the carrier power within the regulatory limits.

KEYWORDS: Space time coding, Multipath channel, Power line channel, Impulse noise, BCH coding

I. INTRODUCTION

Power Line Communication (PLC) refers to communication of information with power line as the medium for communication. Digital communication has replaced the former analog PLC. Digital data corresponding to information is encoded first with error control coding and then modulated using digital modulation schemes. The modulated data being continuous in time is coupled to the high voltage power line by means of a coupling transformer in series with a capacitor. Similar capacitor transformer pair at the receiver point collects the transmitted data and information is recovered that is useful to operate the receiver device.

The high frequency carrier signal carrying the digital data information when coupled to the power line carrying power with low frequency (50-60 Hz), the line tends to act as antenna and radiates electromagnetic (EM) waves. This feature of EMI (Electro Magnetic Interference) of the line is undesirable, as the EM radiations may trigger or distort the unintended receivers operating in the same frequency range. Therefore regulatory standards put the limit on the carrier power to be injected on the line. CENELEC EN 50065-1 (committee European de Normalization Electro technique (CENELEC), regulation EN50065-1) allows 90-148 kHz and FCC (Federal Communication Commission) allows up to 500 kHz, with a permissible carrier limit of 134 dBμV for industry automation [4].

Different approaches are attempted to reduce the carrier power used for digital communication on power line, in order to reduce the EMI. In this paper, a scheme for modem (modulator demodulator) design is derived to achieve the goal of carrier signal power reduction, for data communication over power lines, for the purpose of substation automation is discussed.

Power line channel for data transmission follows two classifications as

(i). Wideband or Broadband over Power Line Communication (BPLC), to transmit and receive internet data which is further classified as:

- (a) Low voltage (<1 kV) high speed BPLC (>2Mbps) for internet application
- (b) High voltage (>36kV) high speed BPLC (>2Mbps) for internet application

(ii) Narrowband Power Line Communication (NPLC) intended for supervisory or control data transmission on power line which is further classified as:

- (a) Low voltage low speed NPLC for home automaton (<100kbps)
- (b) Medium voltage (1kV – 30 kV) low speed NPLC for industry automation

A substation is said to be automated when it employs intelligent electrical/electronic devices (IED's) for supervisory and control actions. Substation automation can be achieved by communication with IED's using power line. Thus substation automation comes under the class of narrowband PLC. Carrier frequency and carrier power used for digital modulation of the data should be within the regulatory limits specified for NPLC.

In [1], the author mentions the merits of Medium voltage PLC for automation such as emergency and maintenance control, security systems, power network (power grid) management optimization and monitoring systems such as remote metering, power quality measurement and fault survey.

In [1, 2, 3 and 4], authors have explained that the power line channel can be modeled as a multipath channel, as in case of wireless or mobile channel. A multipath channel is also called as fading channel, due to characteristic of fading phenomenon of multipath channel. Fading is the property of instantaneous variation of signal power in a multipath channel.

In [2], the author suggests the idea of exploiting naturally decoupled phases of the power line and power line being referred to as fading channel, so that space time coding can be applied to power line, to use power line as communication medium for NBPL. The simplest of space time code requires two transmitters and one receiver that can be achieved by coupling the same signal to two phases of the line and collecting from one phase.

The use of power line as medium of communication is attractive as the channel is ready to use and no new medium is required to be created and hence cost effective. The impulsive noise present on the line makes the PLC as not so reliable and this requires the use of efficient schemes of modulation and channel coding.

Alamouti's two transmit antenna one receive antenna space-time code [7] has been adopted in various global standards and is used to estimate and detect the modulated data in a fading channel. Space time coding is applied to PLC in this paper to predict the possibly highly corrupted information on the line and to reduce carrier power. Alamouti's code requires the knowledge of channel state or channel transfer function, which is carried out by sending dummy pilot symbols.

Section 2 of this paper is arranged to provide the nature of the transfer function of the power line channel and the associated impulse noise and the details to model them. Space time coding scheme is explained in section 3. Results are discussed in section 4. Conclusions are given in section 5.

II. POWER LINE CHANNEL AND IMPULSE NOISE

PLC is classified as broadband PLC (BPLC) for high speed internet data communication and as low speed narrowband PLC (NPLC) for industry or home automation data communication. Modeling the power line channel is carried out by two main types- multipath model and by using ABCD parameters by different authors. Modeling of power line in this paper is done by multipath model [5].

The power line can be modeled as multipath channel [1, 5]. Any transmission line will have reflections on the line, if impedance mismatches occur. Impedance mismatch is obviously present on line as few tapping points on the power line always switch 'on' or 'off'. The 'on' or 'off' of switching the load points cause the line impedance impairment and causing reflections or multipaths. This makes the channel to be modeled as multipath channel. The magnitude response of channel thus varies with respect to time as well as with frequency making it to be referred to be as time and frequency variant channel [1, 3 and 5].

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

$$H(f) = \sum_{i=1}^N g_i \cdot e^{-(a_0 + a_1 \cdot f^k) \cdot d_i} \cdot e^{-j2\pi f \tau_i} \quad (2)$$

Equation (1) gives the transfer function of the multipath channel and equivalent to (1), (2) gives transfer function of power line channel [5]. g_i in (1) and (2) represents the gain of each path at i^{th} instant, exponent of second term in (2) represents the attenuation of $H(f)$ with respect to frequency and the exponent of third term in (2) represents the delay (phase changes) in the received multipaths at i^{th} instant. N represents the number of multipaths in wireless channel given by (1) and number of disturbance points in a power line channel, given by (2). Thus (2) represents the time variant and frequency variant transfer function of power line channel. d_i are lengths of disturbance points along the power line and dielectric constant of the insulating material is represented by ϵ_r . The pdf (probability density function) of Middleton's Class-A Noise, is given by (4).

$$f(x) = \sum_{m=0}^{\infty} \frac{A^m}{m!} e^{(-A)} \left[\frac{1}{\sqrt{2\pi\sigma_m^2}} \right] \cdot e^{\left(\frac{-x^2}{2\sigma_m^2} \right)} \quad (4)$$

Equation (4) suggests that Middleton Class A noise model [6] that refers to cumulative sum of Gaussian distributions where σ_m^2 is noise variance, 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) with Gaussian noise power σ_G^2 and impulsive noise power σ_{GI}^2 . And $\sigma^2 = \sigma_G^2 + \sigma_{GI}^2$ is the total noise power. The noise x followed by (4) always includes the background Gaussian noise with power σ_G^2 .

In [4], several noise sources that can be found on low- or medium-voltage power grids are explained, such as, for example (i) colored thermal noise, (ii) periodic asynchronous impulse noise related to switching operations of power supplies, (iii) periodic synchronous impulse noise mainly caused by switching actions of rectifier diodes. Reference to different literature, suggests that analysis of power line with impulse noise justifies the check for power line communication performance.

III. SPACE TIME CODING

A multipath channel is also called as fading channel, due to characteristic of fading phenomenon of multipath channel. Fading is the property of instantaneous variation of signal power in a multipath channel.

3.1 Transmit and Receive scheme for space time coding

In [7], inventions of S.M. Alamouti, the so-called Alamouti space-time block codes, filed in 1997 and patented jointly with Vahid Tarokh are explained. Alamouti's code is a 2 transmit antenna space-time code and has been adopted in various global standards.

Figure 1 gives the schematic of space time coding using 2X1 system (2 transmit antennas, 1 receive antenna). Table I gives the transmit scheme for communication system shown in Fig.1

s_0, s_1 are symbols transmitted in two time slots as per Table 1. r is received signal $[r_0 \ r_1]$, H_0 and H_1 are transfer functions of channel 1 and channel 2 respectively, also called as channel states. s_{0e} and s_{1e} are estimates of symbols s_0 and s_1 at time slots t_0 and t_1 at the receiver which are determined by (5) and (6).

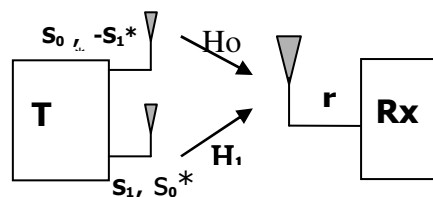


Figure 1. Two transmit one receive space time coding

Table I. Transmit scheme for space time coding

	Time instant t_0	Time instant t_1
Transmitter point 1	symbol 1	-Conj(symbol2)
Transmitter point 2	symbol 2	Conj(symbol1)

$$s_{oe} = \text{conj}(H_0) \times r_0 + H_1 \times \text{conj}(r_1) \quad (5)$$

$$s_{ie} = \text{conj}(H_1) \times r_0 - H_0 \times \text{conj}(r_1) \quad (6)$$

Recovery of symbols s_o and s_i are further found by minimum distance of s_{oe} and s_{ie} with symbols s_o and s_i . The detailed mathematical support to derive receiving scheme is worked in [7]. It is seen that recovery at the receiver requires the knowledge of channel states. Signal estimation and detection at the receiver requires the knowledge of the channel states (Channel State Information). Channel estimation is performed by adding known dummy pilot symbol.

3.2 Power Line as multipath fading channel

The two transmitting antennas in the Alamouti's space time coding scheme can be realized in power line channel, by injecting modulated signal to two different phase lines of power line with respect to earth line by means of capacitive coupled coupling transformers and then by tapping received signal between two phase lines. Equivalent to two fading paths in a wireless channel, the two different paths chosen for signal transmission in power line are statistically uncorrelated and thus make it possible to use the space time scheme.

IV. RESULTS AND DISCUSSION

As per the theory of space time coding applied to fading channel, when signal deteriorates in one path, but is not severely disturbed by any one of other paths, then there should be proper recovery. The same is verified from the results obtained.

The data symbols from information source are first protected by error control coding. BCH code (127, 22), [8] is used to channel code the data. Symbols are then modulated by phase shift keying (PSK) and a carrier frequency within the permissible frequency range used for narrowband PLC. The modulated data then is sent using space time coding as per Table I, and recovered as explained in section 3.

Fig. 2 and Fig. 4 show the plot of magnitude of transfer function in dB (attenuation in dB) of the simulated power line for two different paths. The two paths here mean that one path corresponding to signal propagating via phase 1 of line and path 2 corresponds to signal propagating via phase2 of line.

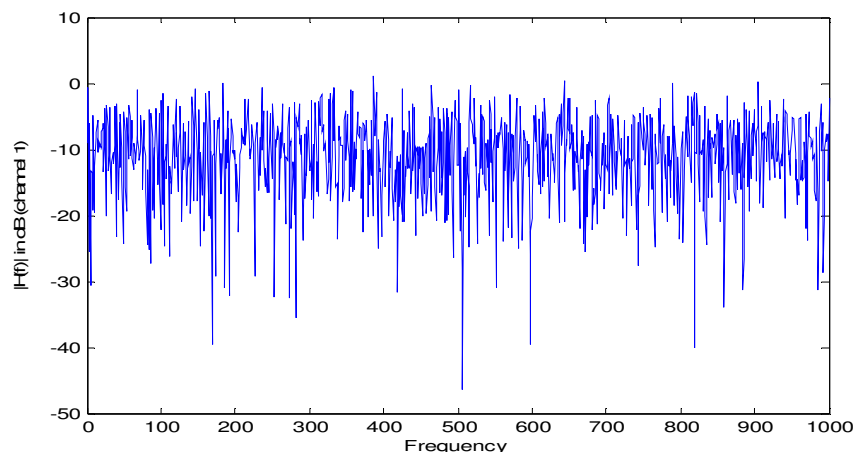


Figure 2. Magnitude of transfer function in path 1.

Table II. Range of $|H(f)|$ in dB with type of attenuation assumed

Range of $ H(f) $ in dB	Attenuation
0 to -5	very low
-5 to -15	low
-10 to -45	medium
-30 to -80	high
-40 to -130	very high

Matlab 7.9 is used to simulate the proposed scheme. Transfer functions of two paths in the power line, are realized using (2), using different attenuation. Table II gives the range of values of magnitude of transfer functions referred to as low, very low, medium, high and very high attenuation, assumed in this paper.

Attenuation at the operating frequency (carrier frequency) is made to change by varying a_0 , a_1 and k , d_i and g_i . Frequency range of 90 to 500 kHz is considered for realizing the channels. The carrier frequency of 200 kHz is used to modulate the data in this paper.

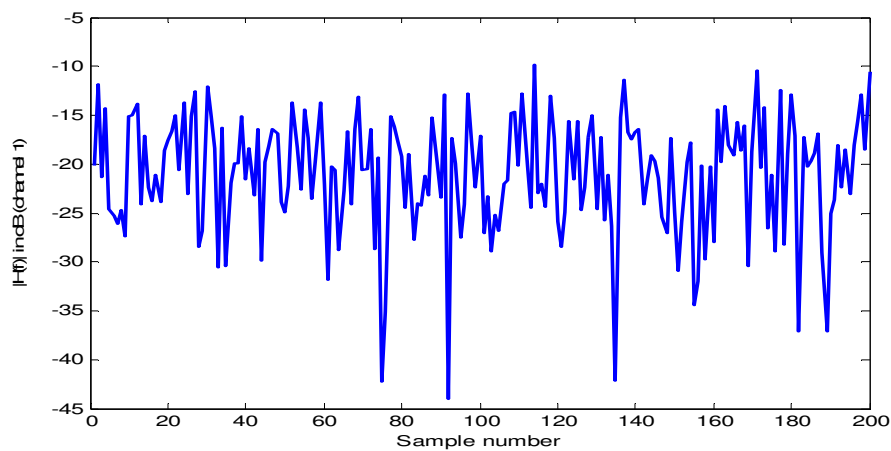


Figure 3. Magnitude of transfer function for path 1 for 200 bits.

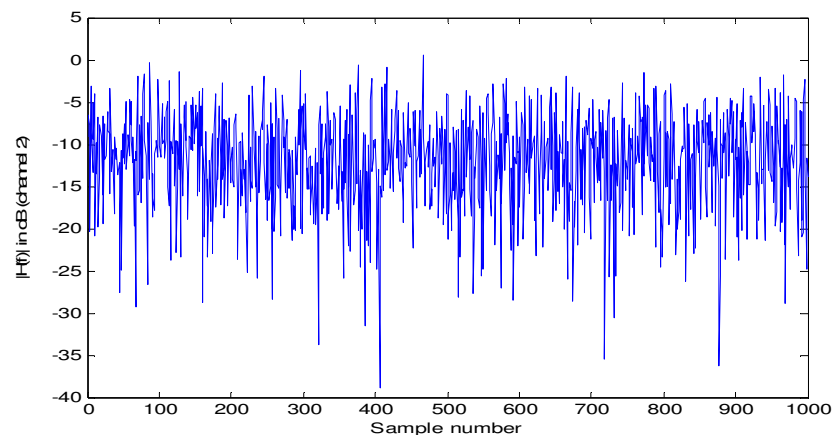


Figure 4. Magnitude of transfer function in path 2.

Time samples of impulse noise simulated using (4) are added to the signal transmitted with channel. In one path going high while the other path being with low and medium attenuation and reversing the situation next time. Data size of the order of 10^4 to 10^5 is used to test the results. Values of A and T are set to 0.1. Numbers of multipaths vary from 2 to 10, with distance between transmitter and receiver being 50 to 200m.

When the digital data is modulated with PSK, with assumed carrier of 200 kHz, the attenuation offered to every bit is shown in Figure. 2. In Figure. 3, attenuation for only 200 bits is shown for clarity, which can be shown for other bits similarly. Attenuations shown by Figure. 2 and Figure. 4,

can now be regarded as two different uncorrelated paths of power line channel. The bits recovered from space time decoding and BCH decoding, are compared with transmitted bits and a graph of probability of symbol (bit) error versus SNR (Signal to Noise Ratio) is plotted. The recovery of symbols is studied for different amounts of attenuation on two paths and Table III was prepared, with reference to Table II.

Table III Consolidated result of the scheme

Data size	A	T	d	No. of paths	Transfer Function in dB		Nature of channel transfer function	Value of SNR in dB for $P_e < 10^{-4}$
					$ H_1(f) $ indB	$ H_2(f) $ indB		
10^4	0.1	0.1	1- 2.5 m	4	Very High	Low	Constant for all bits	13
10^4	0.1	0.1	1- 2.5 m	4	Very High	Medium	Constant for all bits	19
10^5	0.1	0.1	1- 2.5 m	4	Medium	Low	Varying for every symbol	9
10^5	0.1	0.1	1- 2.5 m	4	Medium	High	„	13
10^5	0.1	0.1	1- 2.5 m	4	Medium	Medium	„	11
10^4	0.1	0.1	1- 2.5 m	4	Medium	High	„	13
10^5	0.1	0.1	1-200 m	6	Very High	Medium	„	17
10^5	0.1	0.1	1-5m	6	Medium	Medium	„	15
10^5	0.1	0.01	1-5 m	6	Medium	Medium	„	11
10^5	0.01	0.01	1-5 m	6	Medium	Medium	„	9
10^5	0.1	0.1	1-100 m	14	High	Medium	„	13
10^5	0.01	0.01	1-100 m	14	High	Medium	„	13

4.1 Channel state estimation

The reliability and performance of the proposed scheme depend on successful channel estimation.

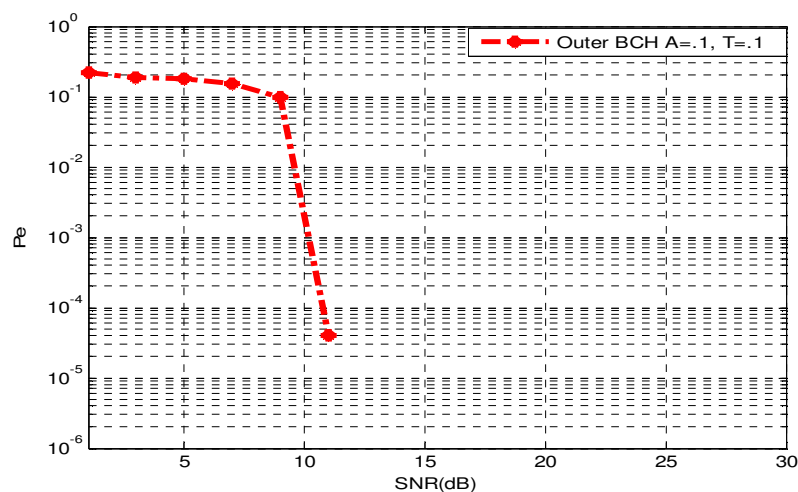


Figure 5. P_e vs. SNR for $A=0.1$, $T=0.1$, 10^5 bits

The knowledge of transfer functions H_0 and H_1 are required at the receiver for signal recovery as given by (5) and (6).

In most of the literature, CSI is assumed. i.e., values of H_0 and H_1 used to send data at transmitter are used as they are, at the receiver. CSI is not assumed as known in this paper. CSI is derived from dummy pilot symbols put along with data symbols.

V. CONCLUSIONS

Table III gives the complete work details and results obtained in this paper. Table III helps to verify the successful data transmission over power line using space time code and BCH code. Error performance of the order of 10^{-5} to 10^{-6} is observed within 20 dB of SNR. Carrier signal level computed at this SNR is found to be within specified limits for narrow band home/industry automation PLC application. In Figure 2, attenuation in path 1, with transfer function $|H_0(f)|$ is varying between 15 to 45 dB and attenuation in path 2, with transfer function $|H_1(f)|$ is varying between 0 to 40 dB, in figure 4. Transfer function for path 1 is shown for only 200 symbols (bits), to view the path attenuation with clarity in figure 3. Attenuation in path 1 and in path 2 can be regarded as medium for industry/home automation PLC application.

Error due to BCH coding which is in outer layer to Alamouti's space time code (inner layer coding), falls rapidly, after few initial values. This is because; the inner code has brought the error in the limits of complete error correction capacity of outer BCH code.

Results show that the system can tolerate the high magnitude impulses and system works well in protecting data from the impulse noise. There are many a versions of modem design using space time coding as in [2], which uses ideal channel state information (CSI). In the work presented in this paper, ideal channel state information is not assumed, but is derived from pilot symbols placed within the data bits. When ideal channel is assumed in the simulation studies, it is found that P_e will be less than 10^{-6} within 3 dB (not shown by plot), for $A=0.1$ and $T=0.1$. This shows that there is scope for improvement in the proposed modem design, if an improved CSI scheme is adopted. To find CSI, many a schemes use a learning sequence, for a length of few bits (or symbols) which may create unnecessary delay or increase in overhead. The proposed scheme does not use a long learning sequence. Also there will be no synchronization problems in this scheme, as the symbol estimation is performed using space time decoding and detection by maximum Euclidian distance in the signal space.

If one of the channel is having low or medium attenuation, then high attenuation in the other channel is tolerated and this holds good alternatively. This verification goes well with Alamouti's theory [7]. i.e., as per the theory of space time coding applied to fading channel, when signal deteriorates in one path, but is not severely disturbed by any one of other paths, then there should be proper recovery.

Error performance of the order of 10^{-5} is observed within 20 dB of SNR. Carrier signal level computed at this SNR is found to be within specified limits ($<134\text{dB}\mu\text{V}$) for narrow band power line communication.

Input of different data sizes are verified to provide the consistent results as tabulated in Table III. Impulse noise parameters are changed to check the error correction. Path lengths in the channel model and the number of paths are changed to verify error correction. Thus an efficient modem design for narrowband PLC is derived.

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