# Space Time coding for Power Line Communication

Rajeshwari Itagi
Research Scholar, NITK, Surthakal, India.
Asst. Prof., Dept. of E&C,
K.L.E.I.T. Hubli, Karnataka, India.
rajeshwariitagi@yahoo.com

Dr. Vittal K P
Prof. & H.O.D., Dept. of E&E,
NITK, Surthakal,
Karnataka, India.
vital_nitk@yahoo.com

Dr. U Sripati
Asoct. Prof., Dept. of E&C
NITK, Surthakal,
Karnataka, India.
sripati_acharya@yahoo.co.in

***Abstract*— A study of Power Line as communication medium for broadband or narrowband application is performed in the perspective of space time coding. Simulation study to send modulated data on two phases of power line and receive signal between two phases and analyze is performed. Middleton class-A noise is used to model the noise on power line. BCH coding is used for error correction. Recovery of data, when at least one path of the channel is with medium attenuation, when simultaneously the other path of the channel goes worse is verified. The results are found to be in accordance with the principle of space time coding scheme and provide the possibility of utilizing power line as effective means of communication.**

***Keywords-space time coding, multipath channel, impulse noise.***

## I. INTRODUCTION

Power line communication (PLC) refers to using the same electric cables used for power delivery, also for communication of information, the application of power line as communication channel being either broadband or narrowband. The powering and signaling circuits are separated by a coupling interface. The conventional way of implementing PLC is to have one transmitter and one receiver. Technically revolutional concepts in wireless communication such as space time coding, given by Alamouti, can be applied to PLC. 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 the signal between two phases.

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. But the regulatory standards [3] limit the carrier power that is used for digital communication of the data. The carrier power needs to be monitored due to the fact that the lines carrying high frequency radiate and cause electromagnetic interferences. The scheme of using carrier power within regulatory limits and still having faithful recovery of data is open to research, as the channel is a harsh channel. Serious degradation of the signal when propagated on the power line takes place, as the channel has transfer function that is both time variant and frequency variant. The impulsive noise present on the line makes the PLC as not so reliable and call for more efficient schemes of modulation and channel coding.

Alamouti's two transmit antenna one receive antenna space-time code [6] has been adopted in various global standards and is used to estimate and detect the modulated data in a fading channel. Space time code is used in PLC in this paper to predict the possibly highly corrupted information on the line. Almouti code requires the knowledge of channel state or channel transfer function, which is carried out by sending dummy pilot symbols.

The paper is arranged to provide the nature of the transfer function of the power line channel and the associated impulse noise in part II and explaining about using the line as 'two transmit and one receive' system in part III. The results are discussed in IV and the inferences drawn from the result are provided in V.

## II. POWER LINE CHANNEL AND IMPULSE NOISE

### A. Classification of PLC

PLC is classified as broadband PLC for high speed internet data communication and as low speed narrowband PLC for industry or home automation data communication. Modeling the power line channel is carried out by multipath model or by use of ABCD parameters. Modeling of power line in this paper is done by multipath model.

### B. Modeling the power line

The power line can be modeled as multipath channel [1]. Any transmission line will have reflections on the line, if impedance mismatches occur. And impedance mismatch is obviously present on line as few tapping points on the power line always switch on or off. This makes the channel to be modeled as multipath channel, in that the on or off of switching the load points causing the line impedance impairment and causing reflections or multipaths. 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.

Equation (1) gives the transfer function of the multipath channel and equivalent to (1), (2) gives transfer function of power line channel [1].

$$H(f) = \sum_{i=1}^{N} g_i . A\left(f, d_i\right). e^{-j2\Pi f \tau_i} \qquad (1)$$

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

$g_i$ in (1) and (2) represents the gain of each path (weighting term), 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. The attenuation and delay are functions of distance of multipath created as a function of time. N represents the number of multipaths. Thus (2) represents the time variant and frequency variant channel transfer function.

Values of gi, di and τi are statistically independent variables. Values of a0, a1 and k are the properties specific to a power line cable. τi is vp / di where vp is velocity of signal propagation given by (3) and dielectric constant of the insulating material represented by $\varepsilon_r$.

$$v_p = \frac{c_o}{\sqrt{\varepsilon_r}} \quad (3)$$

*C. Modeling the impulse noise*

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 Model refers to weighted sum of Gaussian distributions where σm2 is noise variance, with σm2 = σ2 (m /A+T)/(1+T) index T= σG2 /σGI2 is the GIR (Gaussian-to-Impulsive noise power Ratio) with Gaussian noise power σG2 and impulsive noise power σGI2 . And σ2 = σG2 + σGI2 is the total noise power. The noise x followed by (4) always includes the background Gaussian noise with power σG2

In [4], several noise sources that can be found, 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. [5] suggests that analysis of power line with impulse noise justifies the check for power line communication performance.

## III. SPACE TIME CODING AND CHANNEL ESTIMATION

In [6], 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 block code and has been adopted in various global standards.

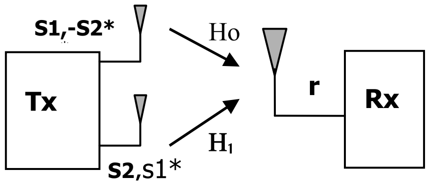


Figure 1 Two transmit one receive space time coding

*A. Recovery of Symbols at the Receiver*

$s_1$, $s_2$ are symbols transmitted in two time slots as per Table 1. r is received signal, $H_o$ are H1 being transfer functions of channel 1 and channel 2 respectively, also called as channel states. $s_{oe}$ and $s_{1e}$ are estimates of symbols $s_1$ and $s_2$ at time slots $t_1$ and $t_2$ at the receiver, which are determined by (5) and (6).

$s_{oe}$ = conj ($H_o$) * r (1, 1) + $H_1$ * conj(r (1, 1)) (5)

$s_{1e}$ = conj ($H_1$) * r (1, 1) – $H_o$ * conj(r (1, 1)) (6)

Recovery of symbols $s_0$ and $s_1$ are further found by minimum distance of $s_{oe}$ and $s_{1e}$ with symbols $s_1$ and $s_2$

The detailed mathematical support to derive receiving scheme is given in [6]. It is seen that recovery at the receiver requires the knowledge of channel states.

*B. Channel State Estimation*

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 within data symbols in this paper. The reliability and performance of the proposed scheme depend on successful channel estimation.

*C. Power Line as multipath fading channel*

The two transmitting antennas in the Alamouti's space time coding scheme can be realised 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 tand 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 statsticaly un correlated and thus make it possible to use the space time scheme.

Table I Space time coding

| | Time instant t1 | Time instant t2 |
|---|---|---|
| Transmitter point 1 | symbol 1 | -Conj(symbol2) |
| Transmitter point 2 | symbol 2 | Conj(symbol1) |

## IV. SIMULATION RESULTS

*A. Simulation Parameters*

The data symbols from information source are first protected by error control coding. BCH code (127, 22) [7] is used to channel code the data. Symbols are then modulated by phase shift keying and a carrier frequency within the permissible frequency range used for narrowband PLC or broadband PLC is used. The modulated data then is sent using space time coding as per Table I, and recovered as explained in section III.

Matlab7.4 is used to simulate the proposed scheme. Transfer functions of two paths in the power line, are realized using (2), using different attenuation parameters for channels Ho are H1. Frequency range of 90 to 500 kHz is considered for realizing the channels. Time samples of impulse noise simulated using (4) are added to receive signal 'r'. The Carrier frequency of 100 kHz (frequency to be chosen within the allotted bandwidth for narrowband PLC) is used to modulate the data. The recovery of symbols is studied for different amounts of attenuations on two paths. Attenuation is varied so as to make the attenuation 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 $10^5$ to $10^6$ is used to test the results. Values of A and T are set to 0.1. Number of multipaths vary from 2-10, with distance between transmitter and receiver being 50 m.

### *B. Results and Discussion*

The results obtained are tabulated in Table II. 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.

In Table II, attenuation in path 2, with transfer function $|H_1(f)|$ is maintained with low and medium and attenuation in path 1, with transfer function $|H_0(f)|$ is varied from low-medium- high-very high. Signal is recovered with signal to noise ratio (SNR) < 20 dB, for the cases of path1 and path 2 suffering from attenuation up to 40 dB. The scheme demands more SNR for cases when attenuation in path 1 becomes high-very high.

Table II: Results for path 2 attenuation moderate and path 1 attenuation low-medium-high

| **A** | **T** | **d** | **Nature of Channel Transfer Function in dB** | | **SNR in dB at which Pe < $10^{-6}$** |
|---|---|---|---|---|---|
| | | | $\|H_0(f)\|$ | $\|H_1(f)\|$ | |
| 0.1 | 0.1 | 1-50 m | -4.5 | -4.5 | 3 |
| 0.1 | 0.1 | 1-50 m | -18.5 | -18.5 | 13 |
| 0.1 | 0.1 | 1-50 m | -32 | -32 | 19 |
| 0.1 | 0.1 | 1-50 m | -42 | -32 | 19 |
| 0.1 | 0.1 | 1-50 m | -46 | -32 | 19 |
| 0.1 | 0.1 | 1-50 m | -64 | -32 | 19 |
| 0.1 | 0.01 | 1-50 m | -70 | -32 | 17 |
| 0.1 | 0.1 | 1-50 m | -70 | -32 | 17 |
| 0.1 | 0.1 | 1-50 m | -92 | -32 | 19 |
| 0.1 | 0.1 | 1-50 m | -94 | -32 | 21 |
| 0.1 | 0.1 | 1-50 m | -124 | -32 | 21 |
| 0.1 | 0.1 | 1-50 m | -138 | -32 | 21 |
| 0.1 | 0.1 | 1-50 m | -200 | -32 | 19 |
| 0.1 | 0.1 | 1-50 m | -236 | -32 | 21 |
| 0.1 | 0.1 | 1-50 m | -130 | -46 | 25 |

The carrier signal computed for SNR below 25 dB, is found to be within the specified limit of 134 dB μV for home/ industry automation.

The same was found true for case when attenuation in path 2 getting worse but attenuation in path 1 being low-moderate as given in Table III.

## V. CONCLUSION

Error performance of the order of 10-6 is observed within 25 dB of SNR. Carrier signal level computed at this SNR provide the signal level to be within specified limits for narrow band home/industry automation PLC application.

Results show that the system can tolerate the high magnitude impulses. With A=0.1, for T=0.01, system requires lesser SNR, which can be justified as for lesser T value, impulse noise variance will be more, but impulses are placed far apart than for T=0.1. System works well in protecting data from impulse noise. If distance is less, performance is better. This is expected as attenuation increases with line length. If one of the channels is having low or medium attenuation, then high attenuation in the other channel is tolerated and this holds good alternatively.

Table III: Results for path 1 attenuation moderate and path 2 attenuation low-medium-high

| **A** | **T** | **d** | **Nature of Channel Transfer Function in dB** | | **SNR in dB at which error Pe < 10 $^{6}$** |
|---|---|---|---|---|---|
| | | | $\|H_1(f)\|$ *in dB* | $\|H_2(f)\|$ *in dB* | |
| 0.1 | 0.1 | 1-50 m | -4.5 | -130 | 3 |
| 0.1 | 0.1 | 1-50 m | -18.5 | -130 | 13 |
| 0.1 | 0.1 | 1-50 m | -28 | -130 | 17 |
| 0.1 | 0.1 | 1-50 m | -32 | -130 | 19 |
| 0.1 | 0.1 | 1-50 m | -40 | -130 | 21 |
| 0.1 | 0.1 | 1-50 m | -45 | -130 | 25 |

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