THE INFLUENCE OF BRANCHES IN THE PERFORMANCE OF POWER-LINE COMMUNICATION SYSTEMS THAT USE MC-CDMA WITH REED SOLOMON CODING

Emmanuel Felix[1], Justinian Anatory[2] and Mussa M. Kissaka[1]

[1]Department of Telecommunications Engineering, University of Dar es Salaam, Tanzania
[2]School of Virtual Education, University of Dodoma, Box 490, Dodoma, Tanzania
E-mail: felix2000th@yahoo.com, anatory@udsm.ac.tz, mkissaka@yahoo.com

ABSTRACT

Power-line network is proposed as an infrastructure for Information and Communications Technologies (ICTs) services provision. However, there are a number of factors that contribute greatly to power-line communication performance degradation. These include number of branches that can be added or removed from the power-line network, lengths of the branch lines, loading etc. It has been pointed out that the number of branches is one of the factors that affects power-line performance to a certain extent. In this paper the influence of number of branches on the performance of Broadband Power-line communication (BPLC) that uses MC-CDMA modulation scheme with Reed Solomon coding is investigated. It is shown that with substantial number of branches at a particular node in power-line a performance BER of 10-6 at SNR of about 25dB with channel capacity of 300Mb/s can be attained

Key words: Power-line broadband application, MC-CDMA performance model, Reed Solomon coding, Probability of symbol error and Channel capacity.

INTRODUCTION

BROADBAND capacity requirements for telecommunication services are still a challenge. Although there are better technologies in use but are still offered at high cost that is not affordable in developing countries. Such technologies are wireless technology (WT), optic fiber technology, Very Small Aperture Terminal (VSAT) etc. Other alternatives have been proposed that could offer cheaper communications to rural areas, one of such areas of opportunity is the power-line network. Power-line is a network for electrical power distribution in cities, town and villages (Pansini, 2005). The system is not intended for high speed signal transmission as there are substantial noise effects caused by the nature of the operations of the power-line systems (Dostert, 1997). Such noises include Rayleigh fading from multipaths effects, impulsive noise, background noise, and Gaussian white/colored noise (Meng and Vinck, 2007). Investigation of better modulation scheme to be used on power-line communication is considered among important things to mitigate noise (Vinck and Haring, 2000; Benyoucef, 2003; Giovaneli et al, 2003; Oshinomi et al, 2003; Cuncic and Bazant, 2003; Amirshash and Kavehrad, 2006; Guerrieri et al, 2007). The use of multicarrier modulation schemes have shown good performance (Zhang and Cheng, 2004). One of the multicarrier schemes being applied is Orthogonal Frequency Division Multiplex (OFDM). Although OFDM offers attractive performances it has proved not to sustain the noise levels in power-line network and therefore there are still demands to improve the use of OFDM to form a more appropriate modulation scheme in power-line. In order to improve performance a combination of OFDM with Direct-Sequence Code Division Multiple Access (DS-CDMA) to form Multi-Carrier Code Division Multiple Access (MC-CDMA) was suggested (Yee and Fettweis, 1993; Fazel and Papke, 1993). With MC-CDMA signals were modulated through different conventional (M-PSK) modulations and performance of each measured. It was observed that optimum performance was attained using MC-CDMA (DQPSK). Reed Solomon (RS) is considered to be a powerful coding scheme suitable to combat burst errors as available in power-line network. In that the case RS codes are suggested to be applied with MC-CDMA for better performance in power-line network.

The number of branches in power-line is one of the factors contributing to poor PLC performance (Anatory et al, 2006, Anatory et al, 2007(a); Anatory et al, 2007(b)). Preliminary work included testing several modulation and coding schemes to evaluate their performance in power-line network. Such modulations were on M-PSK series ((BPSK, QPSK(4-PSK or 4-QAM), 8-PSK, 16-PSK and 64-PSK)) in which results reveals that MC-CDMA using QPSK modulations scheme is robust enough and sufficient to mitigate noise in PLC. The identified modulation scheme was also applied with different coding schemes (Generic linear codes, Cyclic codes, BCH codes, Hamming codes and Reed solomon codes). It was found out that MC-CDMA with Reed Solomon offers performance close to theoretical estimates and is less affected by the change of number of branches. The aim of the study is to evaluate performance of multi-carrier modulation techniques and identify the one appropriate for broadband provision in Tanzania power-line networks which can achieve Bit Error Rate (BER) 10-6 for lengths greater than 250m at Signal to Noise Ratio (SNR) not exceeding 25dB. To show suitability of MC-CDMA and Reed Solomon coding in power-line networks for sustainable broadband applications.

MATHEMATICAL MODEL FOR MC-CDMA (DQPSK)

Generally for multicarrier OFDM modulation the general symbol error equation is derived from the bit energy per noise ratio given by (1). The parameter T_d, T_g, *nEC, nFFT,* E_b/N_0 *and* E_s/N_0 is actual duration of the valued information, Guard interval time, Number of effective carriers, Number of FFT points bit and symbol energy to noise ratio respectively.

$$\frac{E_s}{N_0} = \frac{E_b}{N_0}\left(\frac{nEC}{nFFT}\right)\left(\frac{T_d}{T_d+T_g}\right) \qquad (1)$$

For normal QPSK modulation schemes the symbol error rate is given by (2) (Proakis, 1995; Proakis et al, 2003). The approximate probability of bit error for DBPSK is given by (3).

$$\oplus 2Q\left(\sqrt{\frac{E_s}{N_0}}\right) \qquad (2)$$

$$P_b = \frac{1}{2}e^{-E_b/N_0} \qquad (3)$$

Since for QPSK and BPSK they have similar single state bit changes (difference between symbol to symbol in the constellations is one bit) therefore the probability of bit error for DQPSK is given by

$P_b = \frac{1}{2}e^{-E_b/N_0}$ likewise the probability of symbol error is given by $P_s = \frac{1}{2}e^{-E_s/N_0}$ substituting the above equation for a carrier within multicarrier application the bit error probability is given as (4).

$$P_b = \frac{1}{2}e^{-\frac{E_b}{N_0}\left(\frac{nEC}{nFFT}\right)\left(\frac{T_d}{T_d+T_g}\right)} \qquad (4)$$

Under multicarrier scheme with N number of carriers the general average probability of errors is given by

$$P_b = \frac{1}{2N}\overset{i=N-1}{\underset{i=0}{\bullet}} e^{-\frac{E_b}{N_0}\left(\frac{nEC}{nFFT}\right)\left(\frac{T_d}{T_d+T_g}\right)} \qquad (5)$$

When background noise and interference signal are taken into consideration the general equation can be

$$P_b = \frac{1}{2N}\overset{i=N-1}{\underset{i=0}{\bullet}} e^{-\frac{E_b}{(N_b+P_j)}\left(\frac{nEC}{nFFT}\right)\left(\frac{T_d}{T_d+T_g}\right)} \qquad (6)$$

Where; $N_0 = N_b + P_j$ Nb is the background noise power and P_j is the interference signal power given by (7). Where parameter A_i is the interfering signal amplitude and W is the PN sequence bandwidth (Proakis et al, 2003). Application of DS-CDMA provides a tendency of spreading/dispreading the signals by a factor L_c given by (8). Where the parameter *R* is the information rate and *W* is the PN code rate. However, the probability of errors for dispread signal and non-dispread signals under QPSK is the same given as equation (2) and (3) . DS-CDMA has an advantage over other modulation methods against interfering signals which also occur in power-line network as they tend to dispread the interfering signals by factor equal to the PN bandwidth (W) (Proakis et al, 2003). Therefore with dispreaded interfering signal the power spectral density J_0 is given by (9).

$$P_j = \frac{A_i^2}{2} \quad (7)$$

$$L_c = W/R \quad (8)$$

$$J_0 = \frac{A_i^2}{2W} \quad (9)$$

For DS-CDMA with the noise level classified into two levels i.e. background noise Nb and interference noise power spectral density J0, the general BER equation for DS-CDMA on QPSK modulations is given by (10).

$$P_{b(DS-CDMA)} = \frac{1}{2} e^{-E_b/(N_b+J_0)} \quad (10)$$

For series of interfering signals with different Amplitudes, J0 can be expressed as (11).

$$J_0 = \frac{1}{2W} \sum_{i=0}^{\infty} A_i^2 \quad (11)$$

The general equation can then be expressed as (12). If the background noise is disregarded (assuming $J_0 >> N_0$) then the DS-CDMA provides an improvement on the signal of factor (.)W. For multicarrier case the probability of an error can be expressed as (13).

$$P_{b(DS-CDMA)} = \frac{1}{2} e^{-E_b/(N_0+\frac{1}{2W}\sum_{i=0}^{\infty} A_i^2)} \quad (12)$$

$$P_b = \frac{1}{2N} \sum_{i=0}^{i=N-1} e^{-\frac{E_b}{\left(N_0+\frac{1}{2W}\sum_{i=0}^{\infty} A_i^2\right)}\left(\frac{nEC}{nFFT}\right)\left(\frac{T_d}{T_d+T_g}\right)} \quad (13)$$

Equation (13) represents Multicarrier Probability Density Function (PDF) based on Additive White Gaussian Noise (AWGN) and interfering signals in power-line channel using multicarrier CDMA scheme. Since power-line has impulsive and multipath fading, a modified PDF needs to be formulated that will represent probability of errors based on impulsive noise, Rayleigh fading together with AGWN

PLC NOISE MODEL UNDER IMPULSE AND RAYLAIGH FADING

Power-line noise as mentioned are also dominated by impulsive noise and background noises involving multipaths with Rayleigh fading due to impedance mismatch and multi-conductor lines. The phenomenon of this forms i.i.d complex noise elements that are circularly symmetrical denoted as $\underline{z}$. The $\underline{z}$ can be expressed as (x+jy) in complex forms. x and y are the in-phase and out of phase wise components

$$\underline{z} = (x+jy), \quad z = |x + jy| \quad (14)$$

From different researchers the power-line impulsive noise is modeled as Middleton's class A noise (Giovanel et al, 2002), (Anatory, 2009). Middleton's class A noise model is the appropriate model presenting noise channel from a channel with impulsive noise and multipaths on Rayleigh fading including components of AWGN like in power-line channel. Using Middleton class A model the PDF $P_n(z)$ can be given as in equations (15-17).

$$P_n(z) = \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right) \quad (15)$$

$$\alpha_v = e^{-A} \frac{A^v}{v!} \quad (16)$$

$$\sigma_v^2 = \sigma_g^2 \frac{\left(\frac{v}{A}\right) + \Gamma}{\Gamma} \quad (17)$$

Where; A(Impulsive index): is the product of the average rate of the impulse and the mean duration of the impulses. v is the number of impulsive noises sources, Γ is the Gauss Impulsive power Ratio (GIR) which represents the ratio between the variance of the Gaussian noise component σ_g^2 and the variance of the impulsive component σ_v^2. As measured from experiments, at an impulse rate of 1/0.1s and mean duration of $1\mu s$, A=10^{-5}. As A becomes smaller the process become Gaussian. For impulse mean duration of $100\mu s$, A = 10^{-3} which represent a moderate impulsive channel.

Under severe power-line conditions, impulse rate is about 100/s while their durations are about 1ms. This means A=0.1 which is considered as impulsive index at worst case power-line scenario. The combined variance of the noise is generally given by (18). Under a single carrier scheme the general probability of bit error is given by (19). For multicarrier application, the general probability of error can be given by

$$E\left\{z^2\right\} = \frac{e^{-A}\sigma_g^2}{\Gamma} \sum_{m=0}^{\infty} \frac{A^m}{v!} \left(\frac{v}{A} + \Gamma\right) \quad (18)$$

$$P_e = \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right) \quad (19)$$

$$P = \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right) \quad (20)$$

PERFORMANCE OF MC-CDMA WITH REED SOLOMON CODING

The general PDF of power-line channel comprising AGWN, impulsive and Rayleigh fading is achieved. Next we proceed to construct a general PDF that incorporates the capability of the Reed Solomon coding in overcoming burst error and lowering the probability of an error occurring. Generally coding has an advantage of lowering the chance of an error from occurring and thus providing power gain over the transmission signals. It is generally known that Reed Solomon is a powerful coding scheme capable of overcoming burst errors in a noisy transmission channel and offers larger power gain. Just as recap, Reed Solomon codes have error correcting

capability of *t* defined as $t = \frac{n-k}{2}$; Where *n* is the

total number of sub-blocks in the codeword block (Codeword length) and k is the number of sub-blocks in the information message to be coded (message

length). n can be expressed as $n = 2^m - 1$ where *m* is the size of bits of the individual symbol sub-blocks.

For a given channel with bit error probability *P* and with Reed Solomon codeword length *n* of *m* size sub-blocks that has t error correcting capability, the final deduced probability of error on applications of Reed Solomon codes on such particular channel can be given as (21) (Sklar, 2008).

$$P_{RS} = \frac{1}{2^m - 1} \sum_{j=t+1}^{2^m-1} j \binom{2^m-1}{j} P^j (1-P)^{2^m-1-j} \quad (21)$$

With the general symbol error probability equation for multicarrier given by;

$$P = \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right)$$, then the

general equation for multicarrier with Reed Solomon coding can be represented as (22).

$$P_{RS} = \frac{1}{2^m - 1} \sum_{j=t+1}^{2^m-1} j \binom{2^m-1}{j} \left(\left(\frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right)\right)^j \left(1 - \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(-\frac{z^2}{2\sigma_v^2}\right)\right)^{2^m-1-j} \right) \quad (22)$$

As stated *z* represent modulus of independent identically distributed values in complex domain denoted as,

$z = \sqrt{x^2 + y^2}$ where $z = \sqrt{x^2 + y^2}$

An equivalent signal in OFDM (Proakis et al, 2003) can be expressed as in (23).

$$v(t) = \sum_{k=0}^{N-1} X_k e^{j2\pi kt/T}, \quad (23)$$

Where X_k represent the magnitude of the transmitted signal. The signal to noise ratio is given by (24),

$$E_b / N_0 (dB) = 10 \log \frac{E}{N} \quad (24)$$

The parameter E represents the total bit's energy across the spectrum and N the total noise energy across the spectrum.

$E \propto X_k^2$ and $N \propto z^2$, therefore it can be represented as follows.

$$\frac{E}{N} = \frac{X_k^2}{z^2} = 10^{0.1E_b/N_0} \Rightarrow z^2 = \frac{X_k^2}{10^{0.1E_b/N_0}}, \quad (25)$$

In terms of the energy to noise ratio (E_b / N_0) dB the probability of error for a multicarrier with RS codes can be expressed as (26), where X_k is the bits magnitude in Volts.

$$P_{RS} = \frac{1}{2^m - 1} \sum_{j=t+1}^{2^m-1} j \binom{2^m-1}{j} \left(\left(\frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{\frac{X_k^2}{10^{0.1E_b/N_0}}}{2\sigma_v^2} \right) \right)^j \left(1 - \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{\frac{X_k^2}{10^{0.1E_b/N_0}}}{2\sigma_v^2} \right) \right)^{2^m-1-j} \right)$$

$$P_{RS} = \frac{1}{2^m - 1} \sum_{j=t+1}^{2^m-1} j \binom{2^m-1}{j} \left(\left(\frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{X_k^2}{2\sigma_v^2 10^{0.1E_b/N_0}} \right) \right)^j \left(1 - \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{X_k^2}{2\sigma_v^2 10^{0.1E_b/N_0}} \right) \right)^{2^m-1-j} \right) \quad (26)$$

Considering MC-CDMA where DS-CDMA takes effect, the general equation is given as

$$P_{RS} = \frac{1}{2^m - 1} \sum_{j=t+1}^{2^m-1} j \binom{2^m-1}{j} \left(\left(\frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{X_k^2}{2\sigma_v^2 10^{0.1E_b/(N_0 + \frac{1}{2W}\sum_{i=0}^{\infty} A_i^2)}} \right) \right)^j \left(1 - \frac{1}{N} \sum_{i=0}^{i=N-1} \sum_{v=0}^{\infty} \frac{\alpha_v}{2\pi\sigma_v^2} \exp\left(- \frac{X_k^2}{2\sigma_v^2 10^{0.1E_b/(N_0 + \frac{1}{2W}\sum_{i=0}^{\infty} A_i^2)}} \right) \right)^{2^m-1-j} \right) \quad (27)$$

Figure 1 shows the performance comparison curves of the derived model and the actual simulations taken through PLC. It can be noted that the derived model match close to the actual simulation taken over power-line.

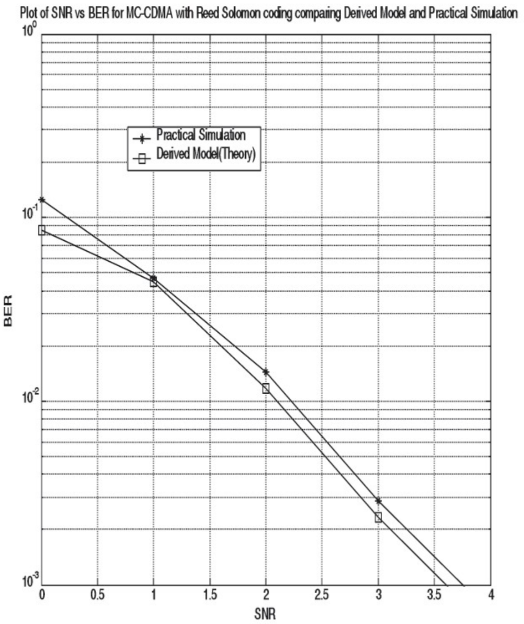

Figure 1: Comparison between Derived Model and Actual Simulated curve on MC-CDMA using Reed Solomon coding in Power-line

PLC CHANNEL SIMULATIONS

Power-line channel has been a challenge to model due to the system uncertainties. Several channel models for power-line system have been devised but yet the majority of them do not meet the correct estimates of signal transfer in power-line systems. Channel model devised by (Anatory et al, 2004) seen to be close to practical results and has been used in this work in determining the characteristic of signal flow in power-line.

Performances on power-line channel with different number of branches have been simulated where the simulation is taken according to configuration shown on fig 2. The branched load (load2) is terminated in 50Ohm load and the branching load (load3) terminated into characteristic impedance of the line. In each case one branch was added to observe its effect on a specific modulation performance in this case MC-CDMA. The length from the source to the load terminals (1000m) was held constant not to affect significantly the attenuation levels. The simulation was carried out with 1 branch, 2 branches, 3 branches, 4 branches, and 5 branches. Medium Power-line channel model (Channel with multi-path) generated by (Anatory et al, 2004) is given by equations (28-30), is used for the simulation work in this paper.

$$H_{mM_T}(f) = \prod_{d=1}^{M_T} \sum_{M=1}^{L} \sum_{n=1}^{N_T} T_{Lm} \alpha_{mn} H_{mn}(f) \quad (28)$$

$$\alpha_{mn} = P_{Ln}^{M-1} \rho_{nm}^{M-1} e^{-\gamma_n (2(M-1)l_n)} \quad (29)$$

$$P_{Ln} = \begin{cases} \rho_s & n=1 (source) \\ \rho_{Ln}, & Otherwise \end{cases} \quad (30)$$

The parameter N_T is the total number of branches connected at arbitrary node "d" and terminated to any arbitrary load, n is number of branches, m is any referenced terminated load, M is number of reflections (with total number of reflections = L), $H_{mn}(f)$ is transfer function between line n to a referenced load m, T_{Lm} is transmission factor at the referenced load m respectively. α_{mn} is the signal contribution factor between load m and branch n.

γ_n is the propagation constant of the branch n. l is the length of branch n. P_{Ln} is the terminal reflection factor for branch n. p_s , p_{Ln} are the source and branch reflection factors respectively. For signal propagation inside the Power-line at particular segment m;

$$V_{final} = H_m(f) * \left(\frac{Z_l}{Z_l + Z_s}\right) V_s \qquad (31)$$

The parameter V_{final} is the measured final signal-voltage at end of respective segment. $H_m(f)$ is the respective transfer function of the referred segment. Z_s is source characteristic impedance

Z_l is the line characteristic impedance of the respective segment and V_s is the source voltage. The multipaths recorded were generated under analytical methods from the channel model as detailed above. The used number of branches, multipaths and their delay times for the simulation are as tabulated in table 1. Simulation was carried out to determine the effect on the performance for different number of branches as added to a specific node as shown in fig.2. Simulation results for the multipaths recorded are shown on figs. 3-7.

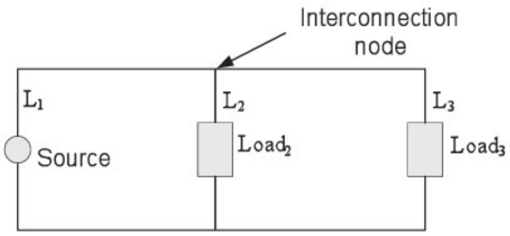

Figure 2: Simple medium power-line network with one interconnection branch

Table 1: Table of results for multipaths effects on branch

Number of branches	Multipath	Delay times (s□)	Total delay Time(s□)
1	0.50 0.25 0.08	3.34 3.40 3.46	0.12
2	0.36 0.34 0.01 0.05 0.03 0.01 0.07 0.03	3.34 3.41 3.48 3.55 3.62 3.69 5.51 5.52	2.18
3	0.25 0.33 0.13 0.07 0.01 0.05 0.008 0.01 0.01	3.34 3.40 3.46 3.52 3.58 5.00 5.06 6.70 6.76	3.42
4	0.18 0.30 0.22 0.04 0.02 0.01 0.07 0.012 0.03 0.02 0.01 0.02 0.004 0.003 0.003 0.004	3.34 3.40 3.46 3.52 3.58 3.64 4.70 4.76 4.82 4.88 6.02 6.08 6.14 6.20 7.35 7.41	4.07
5	0.125 0.24 0.27 0.025 0.01 0.07 0.125 0.05 0.005 0.02 0.04 0.01 0.01 0.001	3.35 3.41 3.47 3.53 3.59 4.45 4.51 4.57 4.63 5.55 5.61 5.67 6.75 7.85	4.50

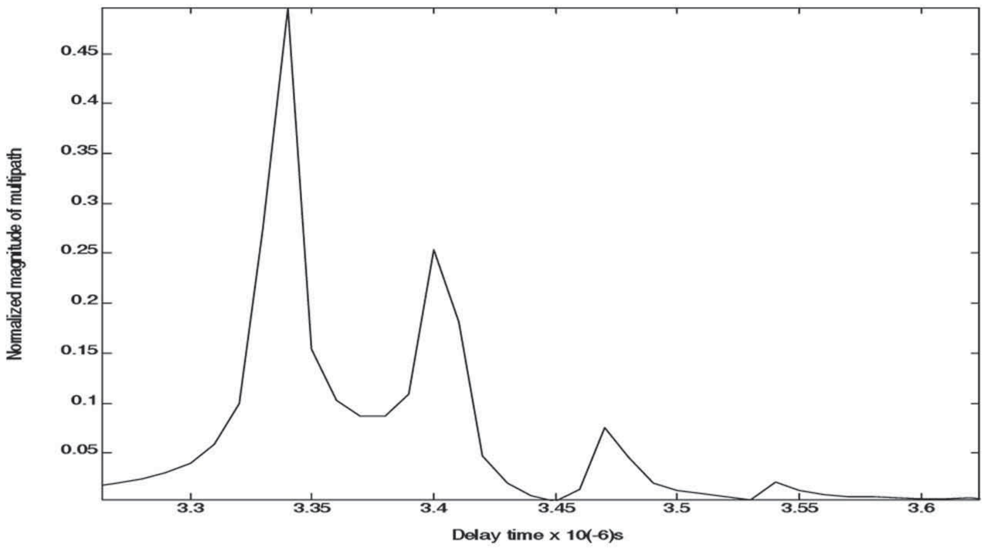

Figure 3: Multipath for PLC with one branch interconnection

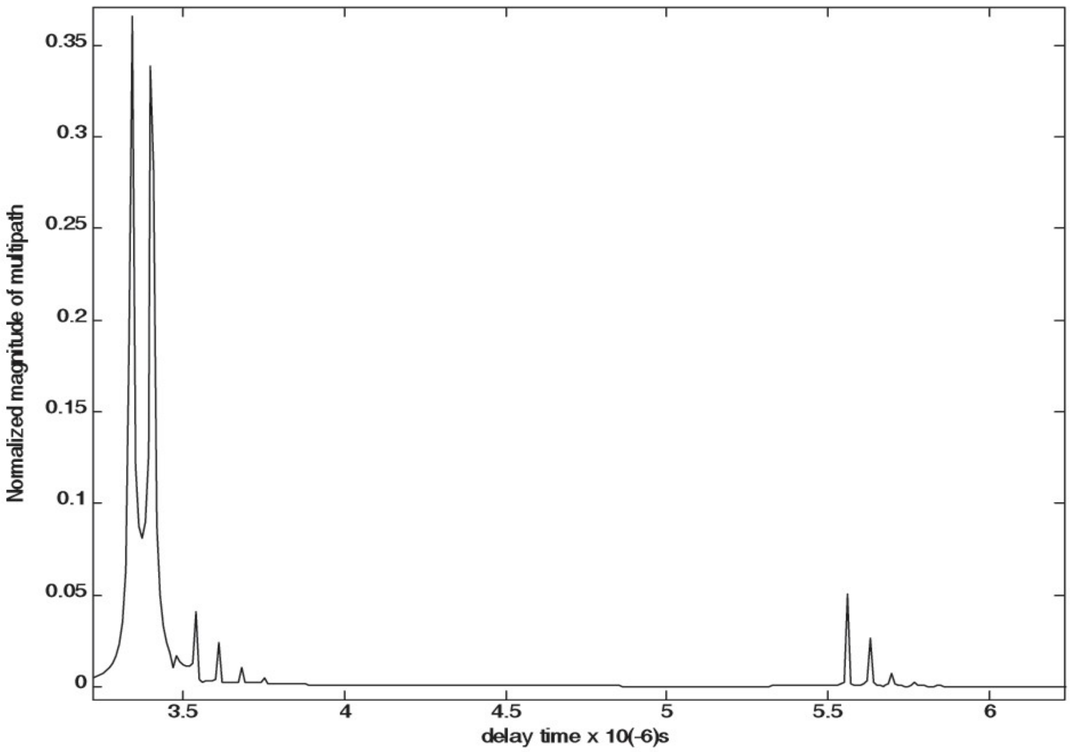

Figure 4: Multipath for PLC with two branches interconnections

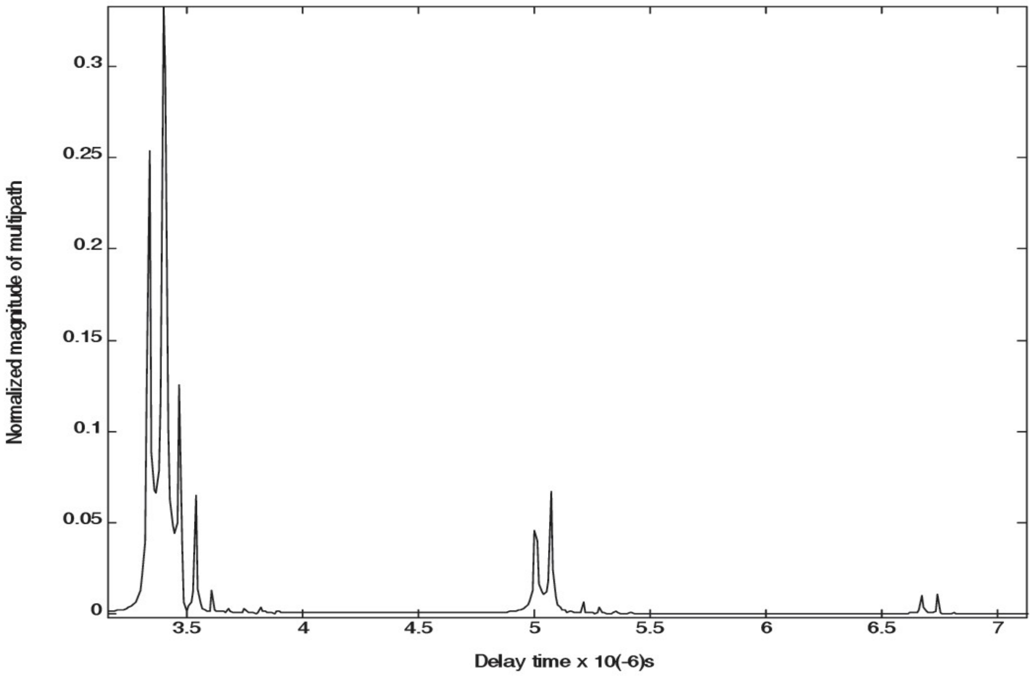

Figure 5: Multipath for PLC with 3 branches interconnections

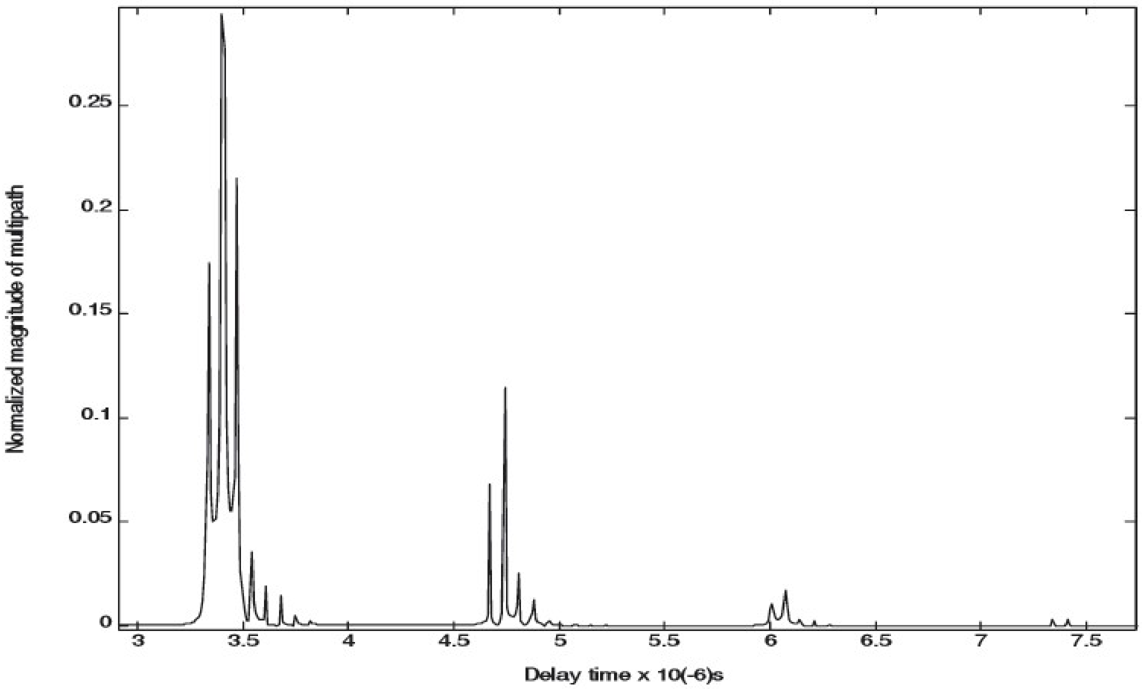

Figure 6: Multipath for PLC with 4 branches interconnections

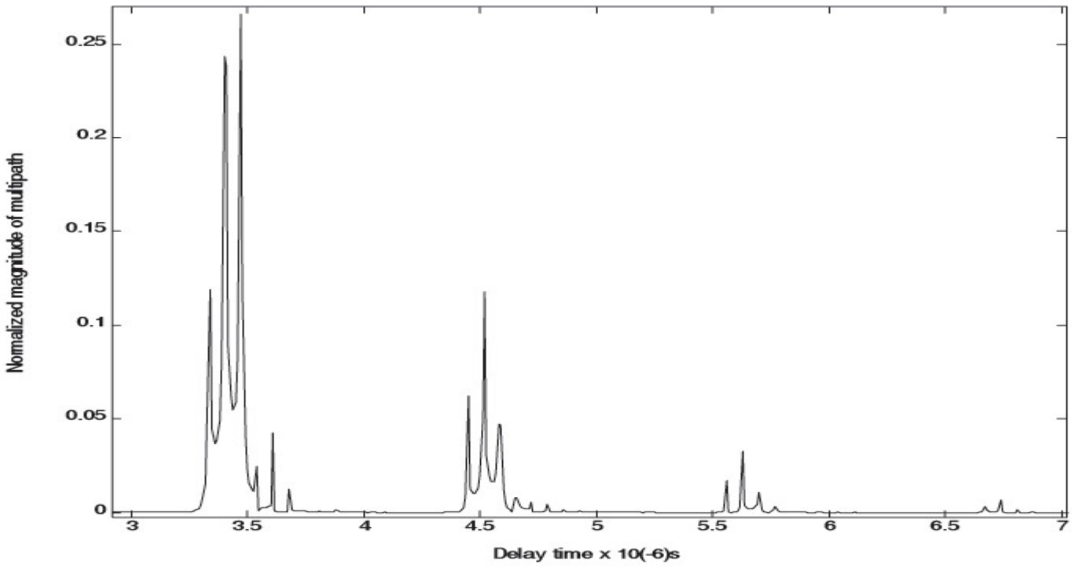

Figure 7: Multipath for PLC with 5 branches interconnections

PERFORMANCE EVALUATION

The results showing performances of MC-CDMA with Reed Solomon coding as affected by number of branches in power-line network is shown on fig. 8. A comparison of different coding schemes using MC-CDMA was done and the results are shown on fig. 9.

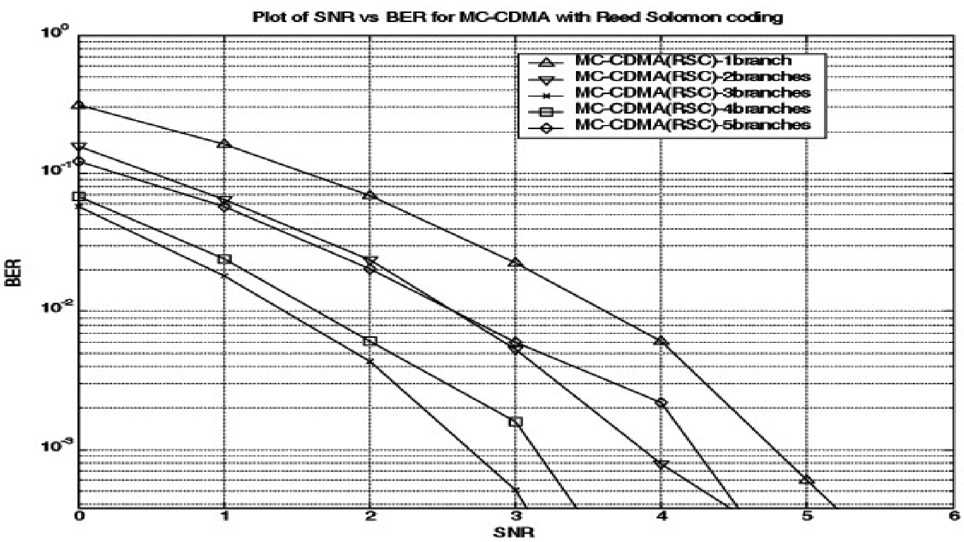

Figure 8: Simulation results for MC-CDMA applying Reed Solomon codes on medium Power-line network with varying the number of branches (Using analytical and Monte Carlo method)

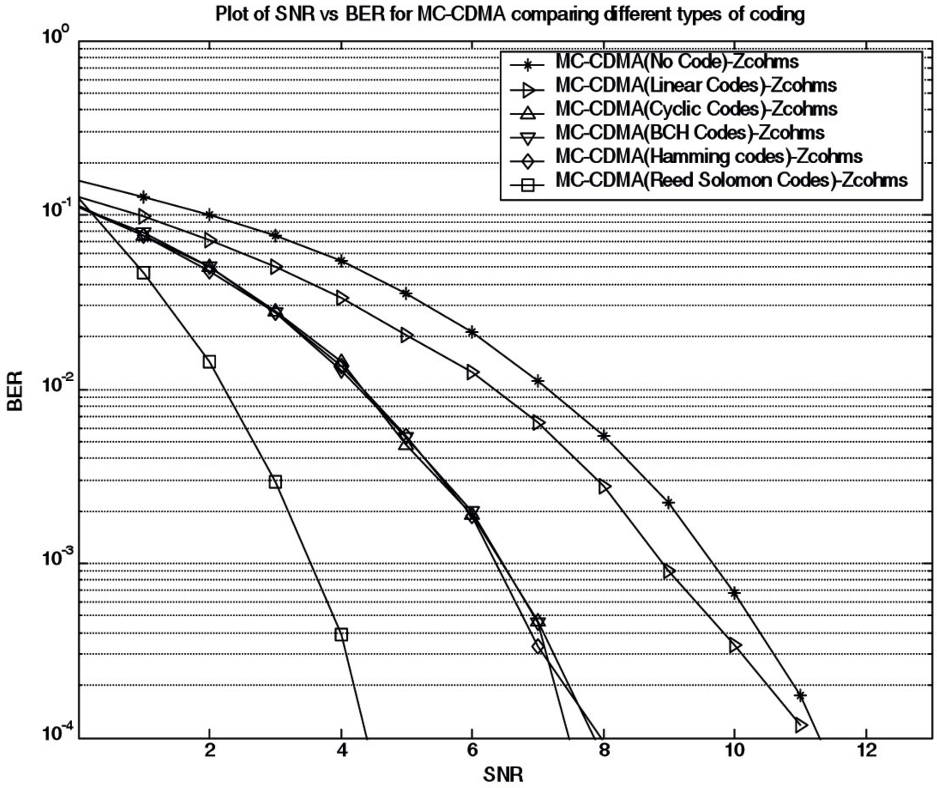

Figure 9: Performance comparisons of different coding schemes applied in power-line

CHANNEL CAPACITY

Channel capacity is explained under Claude Shannon rule as the measure of the upper bound of information flow in a channel medium such that information flow below the limit makes it possible to control the data to have minimal error or nearly zero error at the receiver. The converse is also true such that information flow above the upper bound point of the channel may lead to uncontrollable error rate or complete loss of the information. The equation for channel capacity from Claude Shannon rule is given in equation 32.

$$C = B\log_2(1+\frac{S}{N}) \quad \text{[Mb/s]}, \qquad (32)$$

Where S represents the signal power in Watts, N the noise power in watts taken differently while B stands for the bandwidth of the signal via the medium. The bandwidth applied was 20MHz this is according to CENELEC standards on power communications (1MHz-30MHz). Different channel capacities are evaluated based on the equation and tabulated in Table 2, The tabulated capacities are achieved based on following steps.

$SNR(dB) = 10log10(P/N)$, where P = the signal power and N = Noise power over the spectrum.

Therefore P/N = $antlog\ (SNR/10) = 10^{SNR/10.}$ Channel Capacity become,
$=Blog2(1+10^{SNR/10}) = 3.322Blog(1+10^{SNR/10})$ *where* B = 20MHz.

For channel bandwidth of 20Mhz at SNR of 25dB the channel capacity is,
$C = 3.322Blog(1+10^{25/10})$ = 161.2Mb/s.

Deriving SNR from above equation we get,

$$SNR = \frac{C}{3.322B} * 10 = 3.01\frac{C}{B}$$

$$C = 0.3322 * B * SNR$$

At bandwidth of 20MHz to reach channel capacity C=300Mb/s, SNR needs to be 46.6dB.

It has been observed that at optimum transmit power that will provide SNR of 25dB, the maximum channel capacity attained is 161.2Mb/s, additional gain of SNR can be used to provide additional channel capacity. Application of MC-CDMA and coding provides power ratio gain (this case SNR) that can be utilized to arrive at higher capacity. Any gain from 25dB can be used to calculate capacity that can be added to 161.2Mb/s. Table 2 shows additional SNR gained on applying MC-CDMA with different coding schemes and each gain of SNR obtained is used to calculate the additional capacity of the channel at 25dB.

Table 2: Different coding performance using MC-CDMA for Power-line communications

Coding type	SNR (dB)	Regained SNR (dB) from 25dB	Regained Channel Capacity (Mb/s)	Max. capacity at SNR of 25dB (Mb/s)
No coding	11.5	13.5	89.69	250.89
Generic linear code (4,2)	11.0	14	93.02	254.22
Cyclic codes (7,4)	9.0	16	106.30	267.5
BCH codes (7,3)	8.0	17	112.95	274.15
Hamming codes (7,4)	7.0	18	119.59	280.79
Reed solomon codes (7,3)	4.2	20.8	138.20	299.40

CONCLUSION

According to performance observed above it shows that the performance of modulations is highly affected by number of branches in a power-line node. It can be observed that for every addition of a branch around 2dB is required to maintain the same performance. From the obtained results it is observed that addition of up to 5 branches may results in to loss of 5-8dB if the same performance is maintained. The measurements were made up to addition of 5 branches at a single node. However, as the number of branches increases the multipaths increases i.e. the nth order (n approaching infinity). At optimum number of IFFT points the MC-CDMA modulations can still be sufficient to overcome the significant parts of the multipath streams.

In a simulation of up to 5 branches a performance BER of 10-6 was achieved using MC-CDMA (DQPSK) with RSC. MC-CDMA proves to be the next generation of modulation on power-line communications due to its capability in combating noise. MC-CDMA takes advantage of OFDM and DS-CDMA together to form a super multicarrier modulation scheme over PLC. It can also be observed that Reed Solomon coding provides a powerful tool that can mitigate the power-line noise when applied with MC-CDMA. With larger margin of gain over other coding scheme applied with MC-CDMA it can achieve a transmit rate close to 300Mb/s at SNR level of about 25dB. This proves that despite worst characteristics power-line has RS codes and MC-CDMA stands as powerful coding and modulation schemes that can mitigate power-line noise and provides sufficient rate for broadband applications.

This concludes that MC-CDMA when applied with Reed Solomon codes can substantially offer good quality of data communication over power-line.

REFERENCES

Amirshash, P. and Kavehrad, M. (2006), "High-Frequency Characteristics of Overhead Multi-Conductor Power-lines for Broadband Communications", IEEE journal on selected areas in Communications, Vol. 24, No. 7, July 2006, pp. 1292-1303.

Anastasiadou, D. and Antonakopoulos, T. (2005), "Multipath Characterization of Indoor Power-line Networks", IEEE Transaction on Power Delivery, Vol.20, No. 1, January 2005, pp. 90-99.

Anatory, J., Mvungi, N.H. and Kissaka, M.M. (2003), "Performance Evaluation of Different MAC Protocols for IP based Power-line Communication Networks in Developing Countries", Proceedings of 7th International Symposium on Power-line Communications and its Applications, Kyoto, Japan, March 26th to 28,th 2003, pp. 160-166.

Anatory, J., Mvungi, N.H. and Kissaka, M.M. (2004), "Analysis of Power-line Channel Model for Communication from the Primary Substation Node to End User", Iranian journal of Electrical and Computer Engineering Vol. 3, No. 1, Winter spring, 2004.

Anatory, J., Mvungi, N.H. and Kissaka, M.M. (2006), "Power-line Communications: The Effects of Branches on Network Performance", Proceedings of IEEE-ISPLC2006, Florida, USA, March 2006, pp. 70-75.

Anatory, J., Mvungi, N.H., Kissaka, M.M. (2007(a)), "The Effects of Load Impedance, Line lengths and Branches in the BPLC-Transmission Lines Analysis for Medium Voltage Channel", IEEE Transaction on Power delivery, October 2007.

Anatory, J., Theethayi, N., Thottappillil, R., Mvungi, N.H., Kissaka, M.M. (2007(b)), "The Effects of Load Impedance, Line Lengths and Branches in the BPLC-Transmission Lines Analysis for Indoor Voltage Channel", IEEE Transactions on Power Delivery, Vol. 22, No. 4, 2007, pp. 2150-2155.

Anatory, J., Thethaayi, N., Thottappillil, R., Kissaka, M.M. and Mvungi, N.H. (2008), "Broadband Power-line Communications: Channel Capacity Analysis" IEEE Transactions on Power Delivery, Vol. 23, No. 1, 2008, pp. 164-170.

Anatory, J., Thethaayi, N., Thottappillil, R., (2009), "Effects of Multipath on OFDM Systems for Indoor Broadband Power-Line Communications Networks", IEEE Transaction on Power Delivery, Vol. 24, No. 3, 2009, pp. 1190-1197.

Andrea Goldsmith (2005), "Wireless communications" Cambridge University Press Book, pp. 228-566.

Bahai , R. S. A., Saltzberg, R. B., Ergen, M. (2004), "Multi-carrier Digital Communications: Theory And Applications Of OfdmÐ" Edition: 2, Book published by Springer, 2004.

Banwell, T.C. and Galli, S. (2001), "A New Approach to the Modeling of the Transfer Function of the Power-line", IEEE transaction on Communications", ISPLC 2001, pp. 319-323.

Banwell, T. and Galli, S. (2005), "A Novel Approach to the Modeling of the Indoor Power-line Channel: Part 1: Circuit Analysis and Companion Model", IEEE transaction on Power Delivery, Vol. 20, No. 2, April 2005, pp. 655-663.

Banwell, T. and Galli, S. (2005), "A Novel Approach to the Modelling of the Indoor Power-line Channel -Part II: Transfer Function and Its Properties", IEEE Transaction on Power Delivery, Vol. 20, No. 3, July 2005, pp. 1869-1878.

Couch, Leon W. II (1997), "Digital and Analog Communications". 5th Edition Book, Upper Saddle River, NJ: Prentice-Hall.

Cuncic, P. and Bazant, A. (2003), "Analysis of Modulation Methods for Data Communications Over the Low-Voltage Grid", Proceedings of the 7th International Conference on Telecommunications-ConTel, Volume 2, Issued 11-13 June, 2003, pp. 643 – 648. Dostert, K (1997), "Telecommunications over the Power Distribution Grid; Possibilities and Limitations" ISPLC 1997.

Fazel, K., Kaiser, S. (2003), "Multi-carrier and Spread Spectrum Systems" Book published by John Wiley and Sons, 2003.

Fazel, K. and Papke, L. (1993), "On the performance of convolutionally-coded CDMA/OFDM for mobile communication system," Proceedings of the 4th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '93), Yokohama, Japan, September 1993, pp. 468–472.

Hara, S. and Prasad, R. (1997), "Overview of multicarrier CDMA," IEEE Communications Magazine, vol. 35, no. 12, 1997, pp. 126–133.

Hooijen, O.G. (2000), "On the Relation between Network-Topology and Power-line Signal Attenuation", IEEE transactions on Communications, ISPLCA 2000, pp. 45-56.

Meng, H., Guan, Y.L and Chen, S. (2005), "Modeling and Analysis of Noise Effects on Broadband Power-line Communications", IEEE Transactions on Power Delivery, Vol. 20, No. 2, April 2005, pp. 630-637.

Pansini, A. J. (2005), "Power transmission and distribution", Amazon Books, 2005.

Prasad, R. (2004), "OFDM for Wireless Communications Systems" Book published by Artech House, 2004

Proakis, John G. (1995), "Digital Communications", 3rd Edition, Book published by McGraw Hill (Mcgraw Hill Series in Electrical and Computer Engineering), March 1995.

Proakis, John G., Salehi, M. and Bauch, G. (2003), "Contemporary Communications System Using MATLAB and Simulink", 2nd Edition, Book Published by Brooks/Cole Pub Co, 2003.

Sklar, Bernard (2008), "Digital Communications: Fundamentals and Applications (2nd Edition)", Jan 1 2008, Prentice Hall.

Vincent, Le Nir, and Marc, M. (2006), "A MC-CDMA Iterative Solution for Broadband Over Power-line Communications", 2006 (Article).

Vinck, A.J. and Haring, J. (2000), "Coding and Modulation for Power-Line Communications", Proceedings of the 4th International Symposium on Power-Line Communications, Limerick, Ireland, 5th – 7th April, 2000, pp. 265-272.

Yafuz, E., Kural, F., Goban, N., Ercan, B., and Safac, M. (2000), "Modeling of Power-line for Digital Communications", Proceedings of the 4th International Symposium on Power-Line Communications, Limerick, Ireland, 5th – 7th April, 2000, pp 161-168.

Yee, N., Linnarz, J.P. and G. Fettweis (1993), "Multi-carrier CDMA in indoor wireless radio networks," Proceedings of the 4th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC '93), Yokohama, Japan, September 1993, pp. 109–113.

Zhang, Y. and Cheng, S. (2004), "A Novel Multicarrier Signal Transmission over Multipath Channel of Low-Voltage Power-line", IEEE Transaction on Power Delivery, Vol. 19, No. 4, October 2004, pp. 1668-1672.

Zimmermann, M. and Dostert, K. (2000), "An Analysis of the Broadband Noise Scenario in Power-line Networks", International Symposium on Power-line Communications and its Applications, Limerick, Ireland, April 2000, pp.131-138.

Zimmermann, M. and Dostert, K. (2002), "A Multipath Model for the Power-line Channel", IEEE Transaction on Communications, Vol. 50, No. 4, April 2002, pp. 553