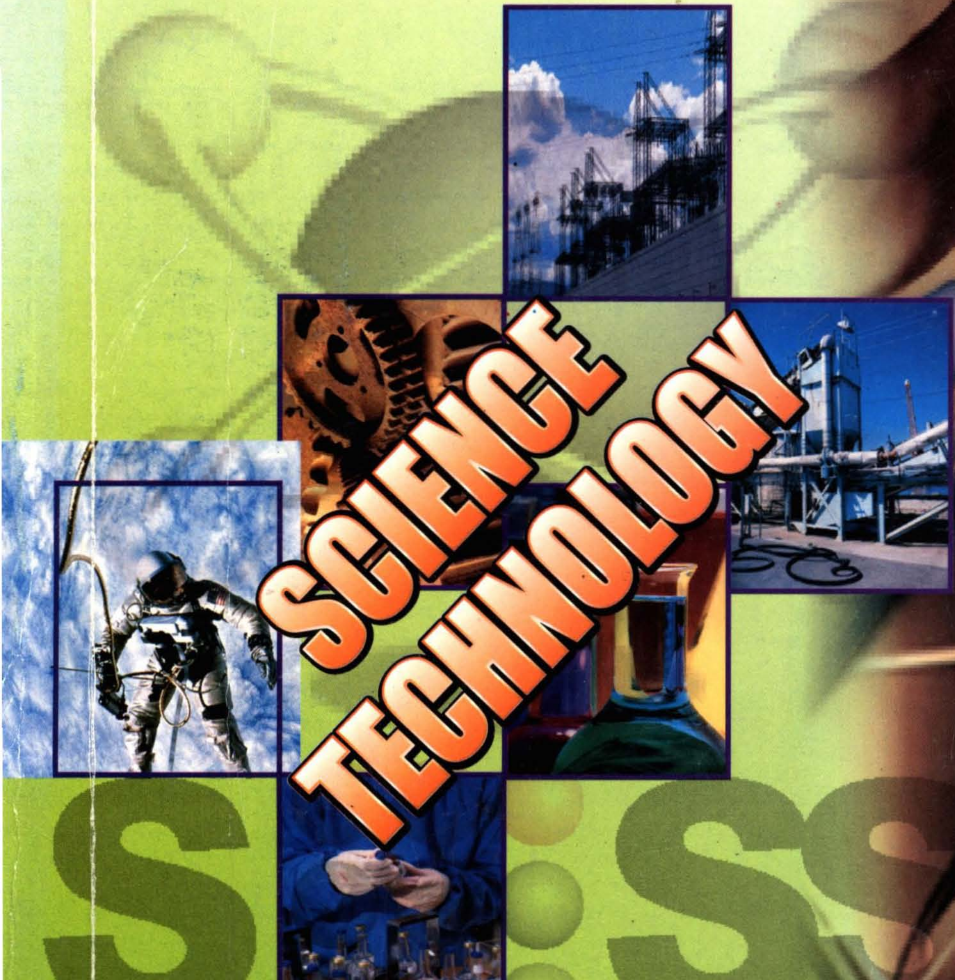
UNIVERSITI TEKNOLOGI MARA

ISO 9001:2000 No Sijil :0500132

# Globalising Knowledge and Information




# NATIONAL SEMINAR ON SCIENCE TECHNOLOGY & SOCIAL SCIENCES 2006

30-31 May 2006

Swiss Garden Resort & Spa

Kuantan, Pahang

# Coding Scheme for a Power Line Communication Channel: A Comparative Study

*Jehana Ermy Jamaluddin*
*Ong Hang See*

ABSTRACT

*Designing a system that is able to withstand unpredictable events is truly a challenging task for data communication engineers. Power lines are potentially convenient and cheap for data transmission; nevertheless, their electrical signal transmission characteristics make it difficult to design even a simple modem. This paper presents the outcome of a study and analysis on various error correction codes to determine the most optimum and practical solution for power line medium. Standard channel model used for testing coding implementation and hardware design is yet to be established. Here, a model with local assumptions and settings is applied. The techniques currently applied are based on some assumptions and settings. The paper reports a compare and contrast of the gain, the bit error rate and the overall performance of the available techniques. Based on the outcome of this study, it is hoped that that more techniques can be discovered and, if not, hybrid techniques can be devised towards a better PLC realization.*

**Keywords:** *Power line communication, coding, error correcting codes*

## Introduction

The power line communication (PLC) is still open to improvements in some key aspects. Despite the demand of new services with higher bandwidth, the 'last mile' technology incurs higher cost of implementation. This forms the main reason why the usage of power grid for communication purposes is being regarded as an expanding field with important market perspectives. Despite the costly setup requirement, many electrical companies are now developing prototypes to be ahead of their competitors especially in PLC devices. The devices are not hardware efficient and, hence, becoming too expensive for the potential market. Therefore, many researchers are still working on special areas on this technology. One of the fields that is quickly becoming the centre of attraction is the modulation and coding techniques that are yet to be standardized. Thus, this paper offers an insight to the available studies made for selecting suitable coding schemes to be applied to the power line carrier.

## Materials and Methods

The information gathered for this research study is obtained from various sources inclusive of research based on simulation and outcomes from related parallel researches in coding mainly.

## Results and Discussions

*Channel model revisited*

A transmission scheme can be optimized once an appropriate channel model is adopted for further work. However, the modeling problem for PLC can be an involved, serious problem, as we need to investigate the characteristics of a power network as a communication channel. Furthermore, there would not be enough models that are so similar to that of any mobile radio channels like the COST models. As a summary, the PLC channels has so much problems as the following (Biglieri 2003):

- Frequency-varying and time-varying attenuation of the medium
- Dependence of the channel model on location, network topology and connected load
- High interference due to noisy loads
- High, non-AWGN and background noise
- Electromagnetic compatibility (EMC) issues that limit available transmitted power.

Some of the channel models developed can be found with the most popular one adopted being the multipath model proposed by Philipps (1999) and Zimmermann and Dostert (2002). It takes the form for $H(f)$ in the frequency range from 500 kHz to 20 MHz (Zimmermann & Dostert 2002). The channel is assumed to be linear with reflections and cancellations with the understanding of the signal does not propagate across in a single path but to have impedance mismatches. Thus, appropriately, the channel is regarded as a multipath environment with frequency-selective attenuation.

Nevertheless, in the indoor environment where it is an in-house implementation, the distance is shorter and there are many bridged taps present at home. So, it results in more frequency notches. The most talk about model for indoor PLC is the one proposed by Banwell and Galli (2003) which is based on transmission line theory. Banwell & Galli (2003) have managed to provide the fact that the PLC channel has predictable features especially for the frequency responses (output impedance of transmitter is equal to the input impedance of the receiver). A more detailed discussion on the channel modeling can be found in Jehana (2004). Thus, the channel model is to be selected before attempting to choose the most suitable coding scheme.

## Disturbances characterization

Before determining the right coding schemes to be used, there is a need to look into the disturbance characterization. As the power cables were designed only for energy transmission, no interest has been shown in the properties of the medium in high-frequency range. Intensive investigation has to be carried out to find out the real characteristics in the transmission medium. Not only considering the distortion of the information signal due to cable losses and multipath propagation, the noise superimposed on the signal energy makes it even difficult to make correct reception.

The first types 1, 2 and 3 as shown in Table 1 have been generalized as one noise class as coloured PLC background noise known as "generalized background noise". While noise types 4 and 5 are classified as "impulsive noise" and as it has relatively higher amplitudes, impulse noise is considered the main cause of burst errors in data transmitted in higher frequencies of the PLC medium.

Since the effects of impulsive noise to the data transmitted across the line are severe, extensive research has been going on to study the noise characteristics by means of channel modeling approach (Hrasnica 2004).

An interesting detail found from reading of Hrasnica et .al. (2004) is that we can go to an extent to develop disturbance model that describes the environment full of disturbances. This gives a thought on how to manage with the MAC layer design, as it is sensitive to incorrect data transmission especially when the error probability remains and retransmission of corrupted data happens. The discussions on On-Off Model and Complex Disturbance Models for OFDM-based systems are discussed (network-discussion inclined).

There has been a classification of noises detailed as follows.

Table 1: The Noise attributes pertaining to Power Line Carrier

| Type | Noise | Attributes |
|---|---|---|
| 1 | Coloured background noise | o1 Power spectral density (PSD) lower and decreases with frequency<br>o2 Caused by superposition of numerous noise sources of lower intensity<br>o3 Strong dependency on considered frequency<br>o4 Parameters of noise vary over time and frequency |
| 2 | Narrowband noise | o1 Sinusoidal form (modulated amplitudes)<br>o2 Occupies several subbands, small and continuous over spectrum<br>o3 Caused by broadcast stations (varies at daytime and higher by night – reflection properties of atmosphere) |
| 3 | Periodic impulsive noise, asynchronous to main frequency | o1 Impulses at repetition rate between 50 to 200 kHz<br>o2 Caused by switching of power supplies |
| 4 | Periodic impulsive noise, synchronous to main frequency | o1 Impulses at repetition rate of 50 or 100 Hz, synchronous with main power line frequency<br>o2 Short duration, PSD decreases with frequency<br>o3 Caused by power supply operating synchronously with main frequency i.e. power converters connected to mains supply |
| 5 | Asynchronous impulsive noise | o1 Caused by switching transients in the networks<br>o2 Arbitrary inter arrival time<br>o3 psd can reach values of more than 50dB above level of background noise<br>o4 Principal cause of error occurrences in PLC networks. |

## Modulation

Efficient and robust modulation and coding techniques should be developed to overcome the noise discussed as above. The following table summarizes the findings on the modulation schemes such as Orthogonal Frequency Division Multiplexing (OFDM), single carrier and spread spectrum techniques.

Table 2: Comparison between Modulation Schemes for Power Line Carrier

| Technique | OFDM | Single Carrier | Spread Spectrum |
|---|---|---|---|
| Bandwidth | Optimal bandwidth utilization | Moderate | Moderate |
| EMC compatibility | Moderate | Moderate | Good |
| Effects on noise | NA | Noise enhancement - Deep frequency notches prevents use of linear | NA |
| Computational complexity | Relatively complex | MAP/Viterbi complexity increases exponentially with length of impulse response | Complex for DSSS |
| Effects of error propagation | Not applicable | Decision feedback equalizers (DFEs) slows down | Not applicable |
| Bit rate | High | Intermediate | Lower |

## Coding

A channel capacity can be seen by observing the appropriate coding schemes being used for data transmission. As of PLC, the coding schemes are varied as to known standardized (agreed) channel model. The following gives an insight to the techniques available for research.

Table 3: Available Coding Scheme suitability for Power Line Carrier.

| | Code | Attribute (BER/Gain) | Suitability |
|---|---|---|---|
| 1 | Space–Time | Gain of 10 dB at BER of $10^{-3}$ | Suitable |
| 2 | Turbo codes | Good for BER above $10^{-4}$ to $10^{-5}$ | Not suitable |
| 3 | OFDM | Low SNR –bit loading necessary<br>High SNR – higher-order modulation scheme necessary | Most favored |
| 4 | LDPC | BER of $10^{-6}$ for increasing block length | Attractive (Wada 2003). |

The above-mentioned codes are the most attempted for PLC environment. The well-known turbo codes, however, have a weakened performance at lower BERs (error floor). It has decoding delay, which is only good for data but not voice transmission. On the other hand, OFDM performs better if combined with bit-interleaved coded modulation (BICM). (Biglieri 2003). OFDM generates a number of parallel independent AWGN channels. Perhaps, the trend has been set and it looks like the OFDM technique has become a de facto ever since Dostert took a stand in his slides presentation during the International Symposium in PLC last April. In spite of that, many researchers are now moving back to Low-Density Parity Check (LPDC) codes which in turn to be promising for PLC (Richardson 2003).

## Channel Model versus Coding Scheme

With the basic background on the channel model characteristics, comparison to other known channel models can be seen as the following.

Table 4: Channel model overview for selecting appropriate coding scheme

| Channel | Rayleigh fading | AWGN |
|---|---|---|
| Characteristics | PLC can be roughly modeled as Rayleigh fading channel irregardless of modulation format, the error probability for uncoded transmission shows a decay proportional to $SNR^{-1}$. Capacity wise, the Rayleigh fading channel with interleaving is lesser by AWGN channel: coding is beneficial not crucial. The codewords for Rayleigh must have large Hamming and Euclidean distances. | Code design based on evaluation of pairwise error probability of a coded system as the product of two independent terms: Euclidean distance-dependent or code diversity-dependent. |

The choices of coding schemes can also be generalized as in the state of the power line channel. The following summarizes some important attributes.

Table 5: Coding for Different Power Line Channel States

| State of Power | Type of Coding | Benefits | Drawbacks |
|---|---|---|---|
| Burstiness | Integrate with interleaving | Reduce channel memory, disperse error | Delay proportional to block length of code and coherence time of channel |
| Isolated errors and short bursts | Concatenate a convolutional code with Reed Solomon code | Good for limited memory | Insignificant performance degradation with residual errors after decoding |

Also, adaptivity can be introduced to the code for retransmission if there is detection of errors. It can be used to monitor the quality of the channel and to decide on the choice of code rate.

By observation, coding is not enough to protect the data as it goes across the channel. Most of the implemented devices incorporate FEC to improve connection quality in digital communication. Many researchers work on improving network performance by looking into ARQ mechanism such as *Send-and-Wait ARQ*, *Go-back-N Mechanism* and *Selective-Reject*.

Since there are many new approaches to be made available soon, a work based on the ultra-wideband scheme is now being investigated by the author. The outcome will be researched to seek for suitability with the observed channel behaviors.

## Conclusion

This paper has presented some key comparisons between available modulation and coding schemes to provide a platform for suitable coding scheme. Although OFDM looks most favored by researchers, the area still in need to obtain a low-cost implementation to be incorporated in the PLC hardware devices. Despite no standard channel model is made available yet, there has been a lot of competitions among the electrical companies who wish to dominate the existing PLC market. Likewise, the local implementation has also been looking into feasible way of realizing PLC nationwide.

## References

Banwell T.C. and S. Galli (2003). A Novel Approach to Accurate Modeling of Indoor Power Line Channel. Part I: Fundamental Analysis and Circuits Models and Part II: Transfer Function and Channel Properties. *IEEE Transactions on Communications.*

Biglieri, E. (2003). Coding and Modulation for a Horrible Channel. *IEEE Communications Magazine*, 41(5): 92-98.

Hrasnica, H., A. Haidine and R. Lehnert (2004). *Broadband Powerline Communications Network Design.* West Sussex: John Wiley and Sons, Ltd.

Jehana Ermy Jamaluddin and Ong Hang See (2004). Development of Channel Model for Power Line Communication. *SCOReD 2004*, UNITEN.

Phillipps, H. (1999). Modeling of Powerline Communication Channels. *Proc. Int'l. Symp. Power-Line Communication and its Application*, UK: Lancaster.

Richardson, T. (2003). The Renaissance of Gallager's Low-Density Parity-Check Codes. *IEEE Communications Magazine*. **41**(8): 126-131.

Wada, T. (2003). A Study on the effect of turbo codes in cyclostationary Gaussian noise processes. *IEICE Transaction on Fundamentals*. **86**(9).

Zimmermann, M. and K. Dostert (2002). A Multipath Model for Powerline Channel. *IEEE Transactions on Communications*. **50**(4): 553-557.

JEHANA ERMI JAMALUDDIN & ONG HANG SEE, Department of Electrical Engineering, College of Engineering, Universiti Tenaga Nasional, Km 7, Jalan Kajang-Puchong, 43009 Kajang, Selangor. jehana@uniten.edu.my, ong@uniten.edu.my