Data protection and transmission over low voltage in-house power line channel

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Abstract

The paper describes communication signal propagation measurement and a simulator for low voltage power line channel modelling. In addition two techniques for frequency hopping spread spectrum (FHSS) systems incorporating low complexity Reed Solomon (RS) decoding are introduced. The simulator performance parameters output for both FHSS systems, are then compared.

1. Introduction

When considering low voltage electricity distribution networks (LVEDNs) as communications channels it becomes necessary to adopt robust transmission systems to protect the transmitted data. Such systems must cater for a wide variety of channel noise events together with the effects of multipath propagation. Therefore the design and cost effective implementation of decoders capable of enabling high, error free, data transmission rates become necessary.

In recent years Multi-Media transmission has become an established area of Information Technology (IT), particularly relevant to business and commerce where the potential for simultaneous transmission of text, sound, still and moving pictures is set to revolutionise the way industry works. It has already found applications in a variety of areas, such as education, video-conferencing, etc. In addition to this, a new application of multi-media communication system can be found in Low Voltage Electricity Distribution Networks (LVEDNs) where such systems enable both the utility and the customer to control and monitor the energy product.

Spread spectrum techniques might be used to improve the quality and robustness of communication systems [1], [2]. By spreading the information signal over a larger bandwidth than is required for normal transmission, the effects of noise and jamming can be reduced, also security of the system may be improved. For example, the spread spectrum signal might be hidden in the noise using direct sequence spreading, or the spread spectrum signal might hop in the frequency and or time domain according to a specified pattern. The use of spread spectrum lends itself well to the application of power line data transmission, as the time and frequency variants of the power line network create problems which spread spectrum techniques are able to overcome. Frequency-hopping M-ary Frequency Shift Keying (FH/MSFK), and Random Frequency-Hopping M-ary Frequency Shift Keying (FH/RMFSK) modems are introduced.

LVEDNs suffer variable attenuation across the spectrum. Furthermore, they may also suffer noise bursts and relatively high attenuation due to their tree and branch configuration.[4, 5]. This paper considers ways of overcoming these problems by the application of spread spectrum techniques together with the appropriate RS coding and trellis decoding utilising a power line simulator.

2. Channel propagation measurement & simulation

The hardware necessary to interface the communication signals to the power line requires to be broadband, passive, should not be too complex and must be intrinsically safe. The LVEDN, when considered as an open channel, might experience significant time variant noise events and frequency specific attenuation.

Any proposed methods of modulation, demodulation, synchronisation, error and source coding will be of paramount importance in protecting the transmission of high speed data over such a potentially hostile communications channel.

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Propagation measurements have been carried out on closed, in-house, electricity distribution ring mains in order to define the characteristics of such networks and the spectrum which might be available for broadband communication purposes.

Figure 1 shows that over relatively short distances, up to 10m, frequencies as high as 150 MHz might be used. Figures 2 and 3 show pockets of available spectrum, i.e. where the incident signal appears above the noise floor are present some 50m from their initial point of injection. In order to minimise radiation from the , in-house, networks injected signal levels were restricted to – 10dBm.

The channel simulator is a computer based mathematical model of an actual channel response obtained from detailed measurements of the channel characteristics. The channel under consideration is first swept and its amplitude/frequency response captured on a spectrum analyser. These characteristics are then stored in the computer database. The impulse and frequency response information is then extracted from the channel characteristics file which is held in the computer database and a digital filter is then designed which matches the channel parameters. This channel model is then placed into the simulator system to give an accurate model of the power line communications channel. The channel simulator may also be used to input a user-defined channel, based on poles and zeros around a unit circle in order to define the digital filter design criteria. This user-defined characterised filter may then be placed in the overall simulator system to define a true model of the channel.

3. (FH/MFSK) systems

Conventional frequency-hopping M-ary frequency-shift keying (FH/MFSK) systems consist of hopping in frequency one of M symbols. Where the symbol is represented by one of M non-coherently orthogonal tones of duration T_s and energy E_s. The M orthogonal MFSK channels are contiguous and are separated in frequency by at least the minimum tone spacing, δf, which is [7,8]

$$\delta f = 1/T_s$$

Together, they represent the MFSK baseband modulation. For a coherent conventional FH/MFSK system, the minimum tone-spacing requirement is half that of a non-coherent system and, therefore, we have $\delta f = 2/T_s$. However, coherent FH/MFSK modulation is more difficult to implement from a practical point of view.

The spreading in FH/MFSK system is simply achieved by multiplicative modulation. That is by multiplying the MFSK baseband by a data-independent FH tone at every hop. Non-coherent MFSK modulation is assumed.

At the receiver, the incoming signals is de-hopped and demodulated. De-spreading is achieved by heterodyne multiplication between the frequency-hopped signal, r(t), and the FH tone reference at a given hop in the mixer. Baseband demodulation is accomplished by feeding the de-hopped signal in to a bank of M pairs of matched filters. Each pair of matched filters is tuned in a channel. Since non-coherent modulation is used, a pair of matched filters is needed for each channel to retrieves the in-phase and quadrature components of the baseband signal. Then, the in-phase and quadrature components are squared and added to obtain energy output. The highest energy output corresponds to the symbol.

Conventional frequency-hopped (FH) with M-ary frequency-shift-keyed (MFSK) modulation is essentially a conventional MFSK scheme in which the carrier frequency is pseudorandomly hopped over the spread spectrum bandwidth, W_{fh}. Frequency hopping does not alter the relative positions of the MFSK tones to one another as they are just shifted to higher frequencies. Random FH MFSK is a more jam resistant approach where M distinct frequency synthesizers are used to individually hop the M-ary symbols, destroying the contiguous nature of an M-ary band. The relative positions of the MFSK tones are altered, as well as being shifted to higher frequencies, at each hop. Random FH/MFSK is a form of independent (switching) modulation. Here, the data, d(t), is quantised in M levels that correspond to the MFSK baseband. Then, the independent modulation results in a SS waveform $c^{d(t)}(t)$, which correspond to M distinct data-related FH patterns. If we have $d(t_i)=d_j$ at a given time (or hop) t_i, where d_j is the actual data value ($d_0 \leq d_j \leq d_{M-1}$) the SS waveform will be $C^{d_j}(t_i)$.

A side effect of the FH/RMFSK modulation is that a sort of frequency interleaving has effectively been carried out on data, which improves the piracy of the communication.

Figure5 shows a conventional FH/MFSK scheme. Figure 6 shows Instantaneous FH/RMFSK Spectrum

4. Trellis design techniques & Results
Trellis design techniques for linear block codes have been under investigation since 1974 [6,11,12]. The problem returned to the public attention in 1988 when Forney [13] introduced the concept of *coset codes* and the *coset trellises* Muder [14] proved that these trellises are minimal and the number of states in the trellis diagram can be minimised by an appropriate reordering of the symbols in the codeword. Such an optimum reordering has been obtained for some particular binary codes, [14,15,16,17,18,19]. However the general solution to this problem, as well as it's extension for the non-binary codes remains unsolved and represents a complex analytical task. In this paper we introduce a technique which allows an efficient design of minimal coset trellises of RS codes based on the Shannon product of trellises and propose a low-complexity trellis decoding technique that makes the implementation of the designed trellises feasible.

A coset trellis for RS codes represents a set of parallel sub-trellises, each one corresponding to one of the cosets of the basic code [9,10,16]. Such a trellis allows a reduction in the decoder complexity since all the sub trellises have identical structure and differ only in the labelling of trellis branches. Concept of the Shannon product of trellises can be applied for the design of minimal coset trellises of RS codes. In order to design a minimal coset trellis, we start with the calculation of the state profile in the minimal syndrome trellis of the *(n, k, d)* RS code. Such a profile can be obtained by the calculation of minimal number of states for every possible splitting point of the trellis. At the next stage the splitting points which have similar numbers of states and represent the generator matrix G in the following format:

$$G = \begin{bmatrix} g1 \\ g2 \\ . \\ gk \end{bmatrix} = [G1.G2...G_{Nc-1} \ ]$$

Where G_i, i=1,2,........N_c-1, has l_i columns and k rows, and l_i corresponds to the splitting points obtained at the previous stage. Each row of G is used to design the trellis diagram of the *(n,l,d)* code over GF(*q*) and the trellis diagram can be obtained as the Shannon product of *k* designed component trellises.

In the following *example we consider* the design of a coset trellis for the (7,3,5) RS code with symbols taken from the GF(2^3). The generator polynomial is :-

$$g(X) = \alpha^3 + X\alpha + X^2 + X^3\alpha^3 + X^4$$

From which the following generator polynomial is obtained.

$$G = \begin{bmatrix} \alpha^3 & \alpha & 1 & \alpha^3 & 1 & 0 & 0 \\ 0 & \alpha^3 & \alpha & 1 & \alpha^3 & 1 & 0 \\ 0 & 0 & \alpha^3 & \alpha & 1 & \alpha^3 & 1 \end{bmatrix}$$

Following the procedure described by Forney [13], the state profile for every splitting point of the trellis can be obtained as N_{synd} = [1,8,64,512,512,64,8,1]. It is apparent that for a given (7,3,5) RS code one can design a number of different (but isomorphic) minimal trellises. One of these trellises may have three depths with the following state and label size profiles:

N_1 = [1,8,8,1] and L_1 = [1,5,1]

while other trellis may have three depths with the following state and label size profiles:

$N_2 = [1,64,64,1]$ and $L_2 = [2,3,2]$

In our example we choose the latter trellis, thus the generator matrix of the code we represent in the following format:

$$G = [G_1 \ \ G_2 \ \ G_3] = \begin{bmatrix} \alpha^3 & \alpha & 1 & \alpha^3 & 1 & 0 & 0 \\ 0 & \alpha^3 & \alpha & 1 & \alpha^3 & 1 & 0 \\ 0 & 0 & \alpha^3 & \alpha & 1 & \alpha^3 & 1 \end{bmatrix}$$

The overall trellis diagram, T, can be obtained as the Shannon product of three trellises, $T = T_1 \ast T_2 \ast T_3$, each one corresponding to a (7,1,5) code, generated by the corresponding row of G. These trellises are shown in Figure7 , It follows that the minimal coset trellis of the (7,3,5) RS code consists of eight identical parallel sub-trellises that differ only in their labelling and each such sub-trellis has eight states and three depths.

Although the designed coset trellises are isomorphic to the minimal trellises, for long RS codes the trellis becomes unfeasible due to it's considerable complexity and storage requirements. Recently the two-stage sub optimum trellis decoding technique has been proposed for low complexity trellis decoding of binary codes [20,21]. We propose a novel two-stage trellis decoding algorithm applicable to RS codes which allows the reduction of decoding complexity without significant loss of the decoding performance. The decoding procedure consists of two major steps:

1. *Identify in which sub-trellis the maximum likelihood path lies.*
2. *Apply the Viterbi decoding algorithm only to the sub-trellis indicated at step 1.*

By using this method the decoder complexity can be reduced by taking advantage of the inherent regular structure of the coset trellises. By varying the number of sub trellises decoded, the system can be made adaptive in response to the amount of channel noise. Figure 4 shows the results obtained over the simulated power line system. At the time of publication of this paper simulation results for two-stage trellis decoding were not available, effort will be made to produce them for the presentation.

5. Conclusions

A new power-line simulator, which utilised communication signal propagation measurements, has been developed. Two techniques for FH/MFSK systems employing RS decoding have been introduced. Simulator performance parameters output for both FHSS system are compared.

Early results indicate that the suitably coded FHSS systems have a robust error performance overcoming some of the problems associated with the power-line communication channel. Also, a coding gain has been identified from the application of soft decision maximum likelihood trellis decoding when compared against hard decision decoding for the system.

The application of low complexity RS decoding and two-stage trellis decoding might further reduce the overall system complexity.

Figures: -

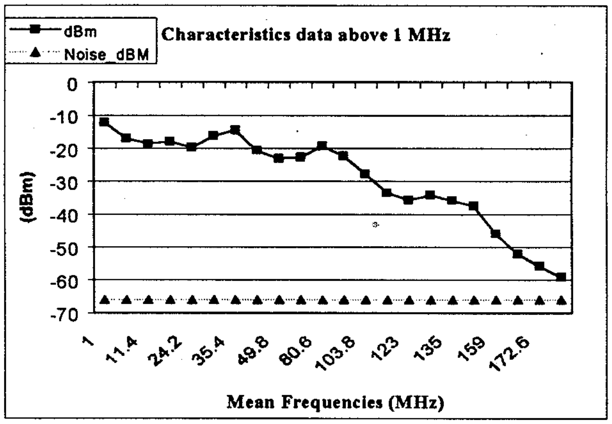

Figure 1(Propagation Characteristics).

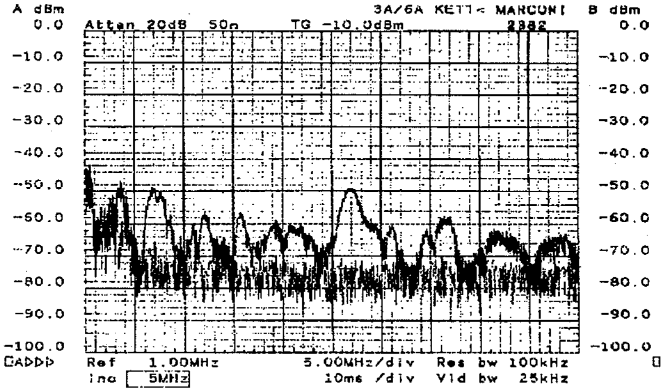

Figure 2 (Usable bandwidth measurements up to 50m)

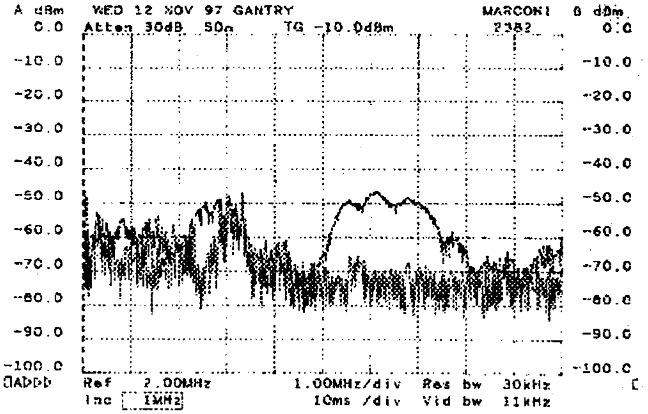

Figure 3 (Usable bandwidth measurements up to 50m)

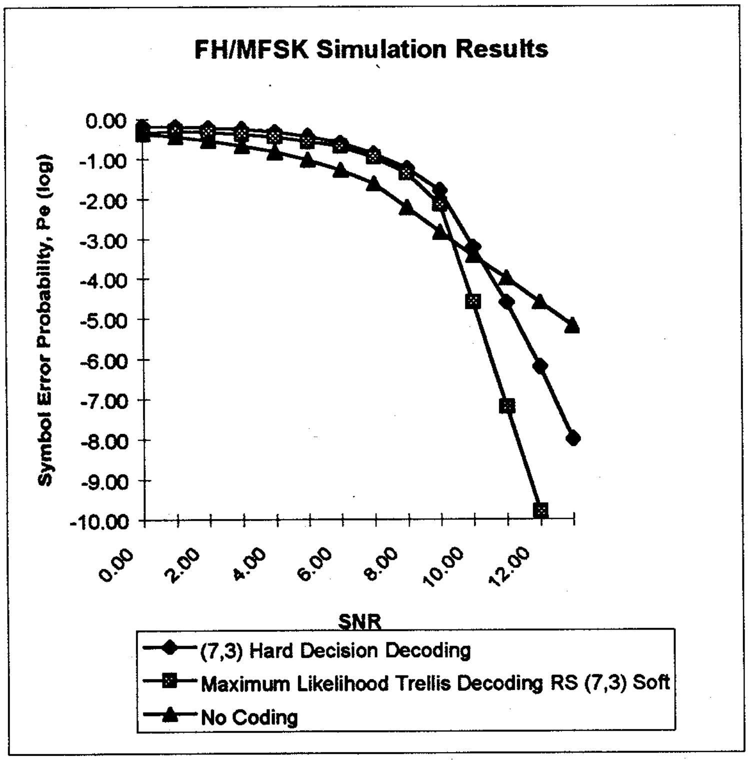

Figure 4 (FH/MFSK Simulation Results)

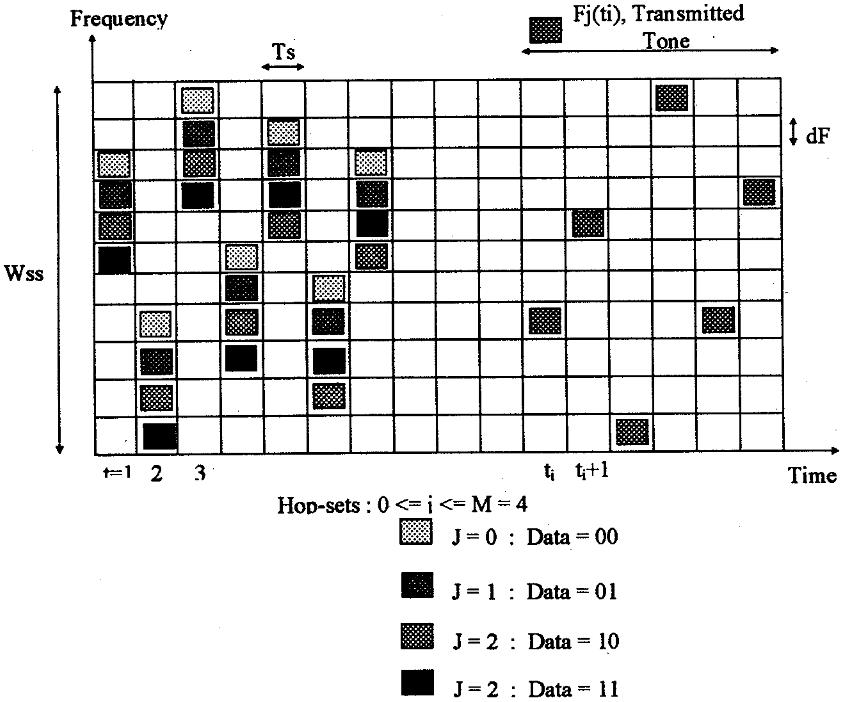

Figure 5 Conventional FH/MFSK Scheme.

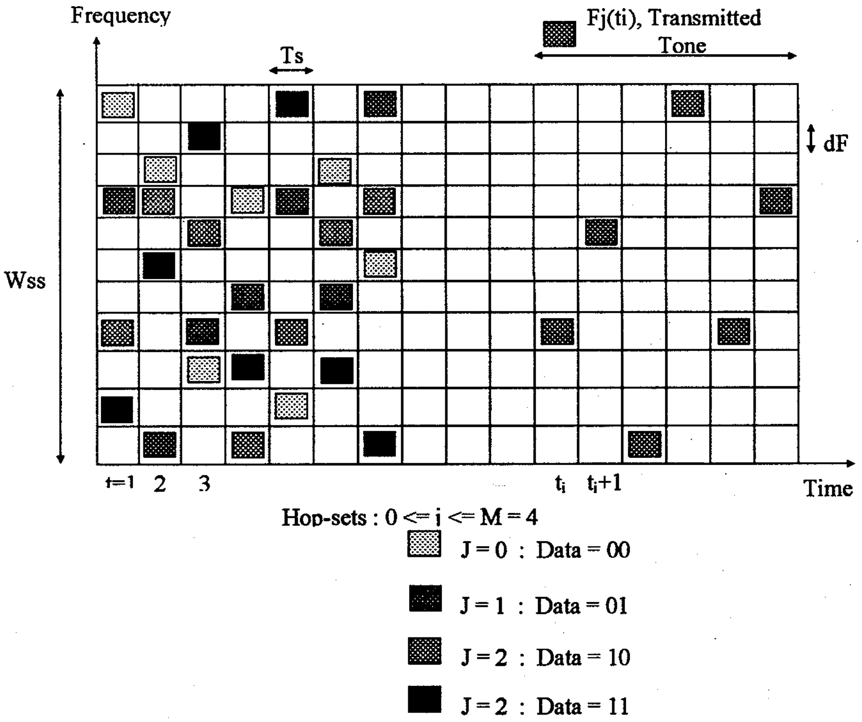

Figure 6 Instantaneous FH/RMFSK Spectrum

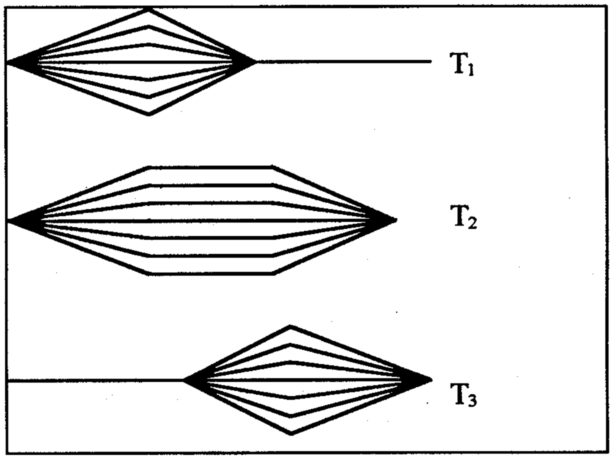

Figure 7 Component coset Trellis for The (7,3,5) RS Code

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