Powerline Communication : Efficient Communication Considerations

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Abstract— This paper focuses on the efficiency considerations while implementing Powerline Communication. The OFDM modulation scheme is deliberated, before introducing the adaptation of Hadamard Coded Modulation. The BER and Peak-to-average ratio (PAPR) of OFDM are discussed in conjuncture with those of Hadamard Coded Modulation. Further discussions are made on reducing DC Bias without significant Information Loss and concept of interleaving for dispersive channels. Security of system is also preconceived.

Keywords- *Powerline Communication, Efficient Communication, Hadamard Coded Modulation, Bit Error Ratio (BER), DC Bias, DC Removal, Orthogonal Frequency Division Modulation, Peak-to-average ratio (PAPR), Hadamard Operator, Hadamard Matrix, Spectral Efficiency, Security.*

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I. INTRODUCTION

Powerline Communication deals with the use of a common network, over which both power and data are communicated simultaneously and asynchronously. The foundation being the sharing of the same conductor network. Though an antiquated concept, it is in recent times that Powerline Communication has gained prominence guided by the widespread applications of Internet of Things (IOT) coupled with the digitization of automobiles and home automation which have thus far been the beacon for implementation of Powerline communication.

The use of existing Powerlines in the network, brings about its own challenges, notable among them being the unfavorable transmission properties, frequency ranges of some MHz that are at the disposal for telecommunication purposes [1], and also the non-redundancy offered by the power grid, which is essential in dense networks for error handling.

Though most of the other limitations can be sidestepped if not fixed the major cause of concern though is to design systems which can achieve reasonable data rate as required (higher Kbits/s to Mbits/s) to optimally utilize the available bandwidth. It is at this stage mandatory to mention that we have in this paper looked at the overall considerations, not any one particular factor in isolation, but rather the entire system's performance as a whole.

Short Hadamard codes of length (L<8) are found to have a good compromise between spreading and complexity [2].

II. OFDM MODULATION TECHNIQUE

For most part of the last few years Orthogonal Frequency Division Multiplexing (OFDM) has been the primary choice for modulation schemes. The OFDM modulation technique however has quite a few drawbacks. Due to its high peak-to-average ratio (PAPR), it is highly susceptible to non-linearities at source, destination, channel and also amplifier. This distortion as expected, gets worse by increasing the average power of the OFDM signals non-linearly since nonlinearity affects larger portion of the signals.

The signal-to-noise ratio (SNR) at the receiver is given by [3]

$$SNR = \frac{\sigma^2}{\sigma^2_n + \sigma^2_{uc}} \quad (1)$$

Where σ^2_n is the power of the discrete-time equivalent additive Gaussian noise. Assuming an M-QAM constellation with square M, the BER is given by [3], [4]

$$BER_{OFDM} = \frac{2(\sqrt{M} - 1)}{\sqrt{M}\log 2\sqrt{M}} Q(\sqrt{3SNR/M - 1}) \quad (2)$$

We contemplate the use of Hadamard coded modulation (HCM) to modulate data as an alternative technique to OFDM.

III. HADAMARD MODULATION TECHNIQUE FOR POWER LINE COMMUNICATION

Keeping the above considerations in mind, we will now look at alternatives: Pulsed techniques have shown to have a good performance in IM/DD optical system with peak power constraints, since they use the sources in their own on/off mode [5]. The Hadamard code is an error-correcting code that is used for error detection and correction when transmitting messages over very noisy or unreliable channels. We can reasonably consider the Powerline Communication Systems to resemble optical communication system discounting the speed while retaining the bandwidth. A perceived problem with these coding techniques like the one listed above is that they have low-spectral efficiency which limits the throughput if not compensated with high bit error rates (BER).

Hadamard logics including Hadamard Operator and Hadamard Tools have emerged as the first-choice tools in communication systems. They reduce BER, decrease PAPR and most importantly the signal immunity to frequency selective fading is boosted [6].

IV. HADAMARD MATRIX

A Hadamard matrix of order n is a matrix Hn with elements 1 or −1 such that Hn Ht n = nIn(eye n). Hadamard codes are considered analogous to Walsh sequences or Reed Muller codes up to interleaving. They have been used extensively in communication systems for synchronization and bandwidth spreading. Hadamard codes provide the coding gain which is relatively low, but can achieve BER at 4 dB, about 6 dB away from the ultimate Shannon limit. The Hadamard Transform requires additions using a straight forward implementation. This cost can be greatly reduced by the Fast Hadamard Transform (FHT) technique [7]

V. HADAMARD CODED WAVEFORM TRANSFER FUNCTION

While implementing Hadamard Coded Waveform, we also have the additional advantage of less hardware complexity, which can be realized by the mathematical representation in terms of its transfer function. Though OFDM, has well established methodology, the challenge exists in implementing the Inverse and Forward Fast Fourier Transform [8]. In virtue of the fact that the Hadamard Matrix exists of only two matrices each of single element -1 and +1, the complex multiplications are discounted.

Let H_N be the binary Hadamard matrix of order N, which is obtained by replacing -1 by 0 in the original {−1, 1} Hadamard matrix [9]. The components of u are assumed to be modulated using M-ary pulse amplitude modulation (PAM). The transmitted vector x is obtained from the data vector as

$$X = (uH_N + (1-u)\overline{H_N}) / \sqrt{N}, \quad (3)$$

Where H_N is the complement of H_N

The matrix $(H_N - \overline{H_N})$ is the bipolar Hadamard matrix, and hence, the first term in (11) is the Walsh-Hadamard transform of the vector u.

Let H represent the generalized Hadamard Transform (GHT), then

$$Y = \hat{H}(x) \quad (4)$$

And the Inverse generalized Hadamard Transform (IGHT) be represented by H*, then we have

$$X = n^{-1} \hat{H}(y) \quad (5)$$

The Hadamard Transform being recursive we define, H_0=1 and then use the below formula to find H_m

(6)

Now assuming Noise to be Additive white and Gaussian, the output can be modelled as

$$Y = \hat{H}(x) + n \quad (7)$$

$$H_m = \frac{1}{\sqrt{2}} \begin{bmatrix} H_{m-1} & H_{m-1} \\ H_{m-1} & -H_{m-1} \end{bmatrix} = H_1 \otimes H_{m-1}$$

$$BER_{HCM} = \frac{M-1}{M\log_2 M} Q\left(\sqrt{\frac{3}{M^2-1}}\frac{\sigma}{\sigma_n}\right) \quad (8)$$

Where σ is the electrical Hadamard Coded Modulation and Q represents the Gaussian Function.

Hence for lower power, the non-linearities as discussed in Introduction have negligible effect on distortion and the performance of Hadamard Coded Modulation is only constraint by Noise.

VI. REDUCING DC BIAS WITHOUT INFORMATION LOSS

The mean value in signal x is very high and hence is removed to enhance the performance in nonlinear systems.
By adding a DC value b_{DC} to the transmitted signal, $y + b_{DC}$ is received instead of y. Then, the decoded vector becomes

$$v = [\sqrt{N} b_{DC}, 0,\ldots,0] + u + \tilde{}n - 1 \quad (9)$$

On adding the DC value to transmitted signal, only first component is affected without changing rest of the data. As mentioned above, we are not sending information on the first component of u, and therefore, we can remove a part of the DC component of the transmitted signal without losing any information. Therefore, in order to increase the power efficiency, we preprocess the transmitted signal in order to set the minimum of each symbol to zero. This modified version of HCM is referred to as DC-removed HCM (DCR-HCM) in this paper. The transmitted signal of the DCR-HCM, x_e, is obtained from x as

$$x_e = x - (\min x) \quad (10)$$

Therefore, $\min x_e = 0$

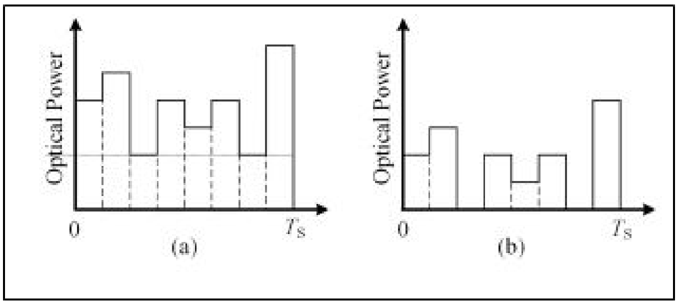

Figure1. Shows an example of DC removal in an HCM symbol, where Ts is the symbol time, x is an HCM signal with min x = 2, and its DC-removed form is obtained by setting x_e = x − 2. As can be seen, the signals of DCR-HCM have lower amplitudes, making them less likely to be clipped by the source.

VII. INCREASING SPECTRAL EFFICIENCY

Spectral efficiency can be increased by implementing pulse shaping functions. In reality, transmission of rectangular pulses requires large bandwidth which makes it spectrally inefficient. To overcome this problem, we use sinc pulses to transmit data instead of rectangular pulses. Since negative pulses cannot be transmitted over the link, a dc bias is added to signals which makes them positive. To make HCM energy efficient dc bias is lowered correspondingly.

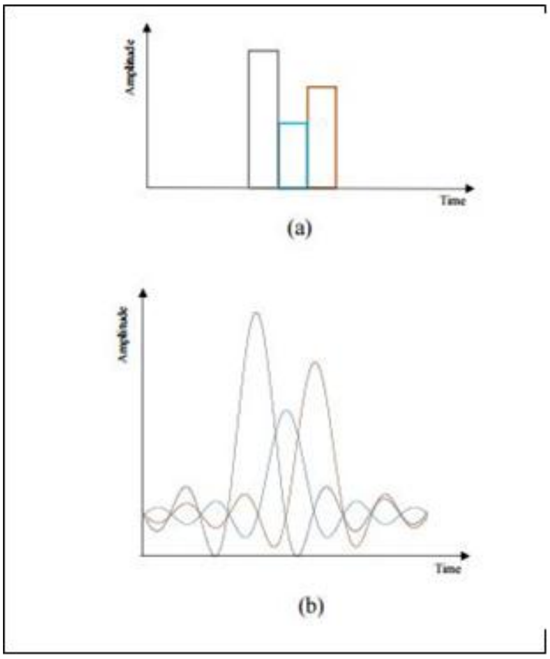

Figure 2(b) illustrates the transmitted pulses for the three rectangular pulses shown in Figure. 2(a).

VIII. INTERLEAVED HCM FOR DISPERSED CHANNELS

Wireless channels are dispersive channels that force inter-symbol interference (ISI) on the transmitted signals, and hence, any modulation technique which is practical, must be renitent against ISI. In Hadamard matrices, some of the rows are cyclic shifts of one another. This makes HCM vulnerable to ISI. Interleaving has been to be an effective solution for this problem [9]. In this technique, as shown in Figure 3, a symbol-length interleaver and de-interleaver are used at the transmitter and receiver. This reduces the effects of intra-symbol interference ISI due to a dispersive channel with discrete impulse response h(k).

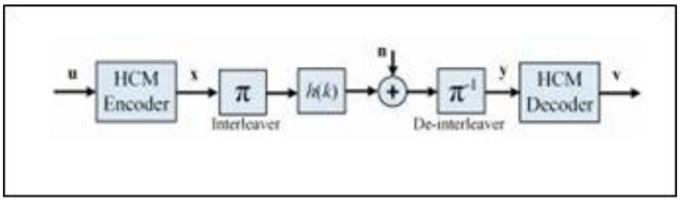

Figure 3. Block diagram of an interleaved HCM system for dispersive channels.

The interleaver is a permutation matrix, π, and de-interleaver is its inverse, π^{-1}. Hence, instead of x, xπ is sent. The best interleaver matrix is the one which evenly distributes the interference over all symbols. It can be obtained using binary linear programming (BLP) [10]. In non-dispersive channels, the performance of interleaved HCM and HCM is same because $\pi\pi^{-1} = 1$. Similar to OFDM systems, cyclic prefix added, decreases the interference between adjacent symbols.

IX. CODING AND SECURITY

The concepts of security mechanisms [read: Cryptography] though applicable at the Presentation layer and above in the OSI model; while the Hadamard Coded modulation is more profound at the lower levels, it is always advisable to consider the implications and suspected behavior of this coded technique and its response to different protocols. Considering the low amplitude (low: PAPR) ratio, we can reasonably expect this coded technique to be stronger to attacks at the system level showing not much variation at the key-level attacks. Hence we propose that Hadamard Coded Modulation is more robust system to be implemented.

X. CONCLUSION

We have in this paper introduced Hadamard Coded Modulation as an alternative to Orthogonal Frequency Division Multiplexing. Hadamard Coded Modulation implements lower signal amplitudes. The lower BER can be attributed to the significantly lower PAPR. Also due to the lower amplitude signal clipping or dc bias removal is not required though preferred for increasing power efficiency.

Furthermore, Hadamard Coded Modulation can be in general used with systems with uninhibited average power.

Increasingly Hadamard Coded Modulation is being used in Optic fiber communication. Practically, it is not possible to cover whole of the bandwidth that optical fiber supports, but this gives HCM a good chance to upgrade the capacity further. Interleaving along with Minimum Mean square error (MMSE) equalization can decrease the BER of HCM by an order of magnitude in dispersive channels, effectively. Hadamard Coded Modulation also has better system robustness to attacks, as preconceived. Hadamard Coded Modulation has commensurate advantages which can make it one of the preferred codes for modulation in Powerline Communication Schemes.

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The authors are undergraduate students, pursuing their third year of Bachelor of Engineering (B.E.) in Electronics and Communication Engineering program at R.V. College of Engineering, Bangalore, India.

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