LOW COMPLEXITY LINEAR PRECODING IN MIMO-PLC SYSTEMS

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Abstract—In this paper, we consider the design of linear precoding in MIMO (multiple input multiple output) PLC (power line communication) system. For that, first we considered mutual information of MIMO-PLC system with impulsive noise. Here we proposed a novel approach to design the precoding scheme for MIMO-PLC system to increase (improve) performance in terms of maximizing mutual information value with low complexity and better speed of operation. Specifically our work primarily includes the following two contributions: (1) we accept right unitary matrix that is product of two fix unitary matrices, which only depend on modulation index. So, the result only depends on modulation mode. And thereby reduces computational complexity. (2) For power allocation matrix, we reduced the computational complexity and improve speed of operation by reducing the iteration for optimization. For that, we used exhaustive search method for maximization of mutual information.

In regards to computational complexity of analysis, we conclude that, the proposed precoding matrix design scheme has low complexity and is easy to implement with better speed. Moreover the numerical results are proven to demonstrate the performance of proposed precoding design scheme.

Keywords—Precoding Design, MIMO-PLC, Impulsive Noise, Finite Alphabet Input.

I. INTRODUCTION

The target of home networking is to connect all the digital electronics consumer devices within home. The consumer should be able to access all services and data at any time, and any place in the home, regardless of where the electronics devices are located. Wireless system works well within a single room. However, there data throughput and reliability decreases dramatically through walls or ceilings especially when made of concrete with metal reinforcement. To enable real broadband throughput for room to room connectivity an in-home backbone network that connects individual devices or clusters in home with minimum installation is desirable. PLC (power line communication) fulfills these requirements. The utilization of 3 wires in conjunction with MIMO (multiple input multiple output) signal processing is capable of boosting coverage and capacity of PLC transmissions.

There are two way to consider the performance of communication in terms of capacity. First is the transmission rates, that is if we can increase bit rates then can have good performance at receiver in case of internet service. And the second way is to increase the coverage area (mainly in case of wireless communication). Applying precoding scheme at the transmitter of PLC with full channel information available, in corporate with MIMO concept enhance the performance in both the ways. It increase coverage area in room with great transmission rates. Specifically in MIMO, mutual information of two random variables is a measure of the mutual dependence between two variables. It quantifies the “amount of information”(bits) obtained about one random variable, through the other random variable. So as the transmitter and receiver antennas increases in MIMO, the value of mutual dependence increases. Thereby increasing the mutual information value. This is the target of this paper.

Aim of maximizing mutual information is fulfilled here by transmitting the signal having pre knowledge of channel and noise. So that we can have less distorted signal at the receiver. So that if we can treat the signal before transmission to inverse the channel effect and to oppose the noise then at the receiver we don’t need to use very complex structured filters to get estimated signal. This phenomenon is called precoding. Precoding is done at the transmitter after modulating the signal and before applying to the communication channel. Here, precoding scheme is proposed for MIMO-PLC environment.

The superscript (.)^H denotes complex conjugate transpose. In addition, | | denotes the Euclidean norm of the matrix or vector, diag(.) and Tr(.) represent the elements and trace of matrix respectively. \( E[.] \) denotes the expectation, which can be scalar, vector or matrix.

The rest of paper is classified as follows. In section 2 the system model is described. Section 3 explains the problem formulation with constraints for the given system. And section 4 proves that the proposed scheme is better than other schemes with numerical and graphical results. And finally, section 5 concludes the whole paper.

II. MIMO SYSTEM MODEL

MIMO communication is well established technique in radio transmission systems and can be equally applicable to PLC by replacing transmit and receive antennas with signal feed and receive parts and radio channel with electrical wiring [14].
Fig. 1 MIMO concept incorporate with PLC[14]

Fig1. Shows PLC-MIMO channel for 3-wire installation (L (Live), N (Neutral) and PE(Protective Earth)). Here signal fed and received differentially between pairs of wires. Mainly 3 feeding possibilities are N to PE, P to N and P to PE. On the receiver side, all 3 differential reception paths are available. 4th reception path ground is created for unbalanced network. So mainly 3*4 MIMO PLC system can be proposed.

So, in MIMO PLC system, the signal $y_n$ received at $n$th receive antenna can be given as

$$y_n = \sum_{m=1}^{M} H_{nm} x_m + Z_n$$

Where $x_m$ is signal sent by $m$th transmit antenna and $Z_n$ is noise received at $n$th receiver. The channel input-output relationship can be described as

$$y = Hx + Z$$

Where MIMO channel matrix $H$ is given by

$$H = \begin{bmatrix}
H_{11} & H_{12} & H_{13} \\
H_{21} & H_{22} & H_{23} \\
H_{31} & H_{32} & H_{33} \\
H_{41} & H_{42} & H_{43}
\end{bmatrix}$$

2.1 Channel Model

The value of $H_{nm}$ (channel coefficient) depends on factors such as material and size, which can be derived by measurements and statistical modeling [1,3,4,5]. For N-path frequently domain channel model to account for attenuation of signal flow can be given by [3]

$$H(f) = \alpha \sum_{r=1}^{R} g_r e^{-j\phi_r} e^{-\frac{2\pi f x_r}{c}} e^{-(a_r n + i f + k)}$$

Where $g_r$ is path gain, $d_r$ is path length $\phi_r$ is random phase for defined path, $a_r$, $\alpha$ & $k$ are the attenuation factors depend on material of channel, $E_r$ is dielectric constant, $G$ is frequency attenuation factor.

The channel characteristics described above of multi-conductor power line YJV 4*35 mm² are given in Ref. [2, 3]

2.2 Noise Model

According to Ref [7], the additional additive noise $Z$ in PLC are of two types 1) Back ground noise and 2) Impulsive noise. Back ground noises like colored noise and Narrowband noises can be easily removed. But impulsive noise is complicated to remove from channel. Because impulsive noise is no longer a stationary noise and modeled as an HMM (hidden markov model) with finite number of states. In this, correlation between the noise samples can be ensured by the transition probability. HMM model can be described by its restricted to m=4 the stationary distribution is $[P_0,P_1,P_2,P_3]$. These probabilities are given by Ref.[7].

$$p(x) = \sum_{m=0}^{M} a_m \exp(-\frac{|x|^2}{2\sigma_m^2})$$

and

$$a_m = e^{-\frac{A_m^2}{m!}} \sigma_m^2 = (\sigma_z^2 + \sigma_i^2) m/A + i$$

$\sigma^2$ is variance of class A noise, $A$ is impulsive index, $T$ is Gaussian to impulsive noise power ratio.

2.3 Transmitted Symbols

For reducing the computational complexity and to make system easy, initially, BPSK & PSK modulation symbols are used as transmitted on symbols.

III. PROBLEM FORMULATION

Let the channel matrix $H$ and the precoding matrix $F$, be known at receiver, the corresponding channel output $y$ has probability density functions of (as given in Ref[8])

$$p(y/x) = \frac{1}{(\pi\sigma^2)^N} \exp\left(-\frac{\|y-HFx\|^2}{\sigma^2}\right)$$

$$p(y) = E_x[p(y/x)] = \frac{1}{M} \sum_{m=1}^{M} p(y/x_m)$$

Where $\|\|$ denotes Euclidean norm. Each input realization $x_m$ consists of $N$ iid Symbols from $m$–ary constellation. Assuming probability of channel in state $m$ (m= 0,1,2,3), is $p_m$ the average mutual information can be expressed as 3.

$$I = \sum_{m=0}^{3} p_m I_m$$

where $I_m$ is mutual information for state $m$. Considering AWGN noise, the mutual information given by Ref[8] is

$$I_m(x : y/H) = \frac{N \log(M)}{M} \sum_{j=1}^{M} E[\log_2 \sum_{l=1}^{M} \exp(-d_{jl})]$$

Where

$$d_{jl} = \frac{\|HF_{jl} + Z_{jl}\|^2 - \|Z_{jl}\|^2}{\sigma_m^2}$$

and

$$e_{jl} = x_j - x_l$$

The $x_j$ and $x_l$ contain $N$ symbols and
Low Complexity Linear Precoding in MIMO-PLC Systems

1) We should use all power to transmission of information because higher power allocation can achieve higher mutual information.

2) If the singular values of two sub channels are different then corresponding allocated power should satisfy inequality.

3) When unitary matrix V is defined as previous, then mutual information function should be a concave function.

Based on these three conditions, we present an exhaustive type of search method with less number of iteration to reduce the computational complexity to produce the power allocation matrix. As described below, optimization algorithm for power allocation matrix is given for different port configuration like 2*2 MIMO PLC system and 3*3 MIMO PLC system. Here, “P_i_up” and “P_i_low” denote the upper bound and lower bound of the allowed power for port I, respectively. In addition “MI_F” denotes the achievable mutual information in case of adopted power allocation matrix P, and “MI_P_i_pre” denotes previously adopted mutual information for P_i.

Table 1: Value of ø_mode for different modulation modes[2]

<table>
<thead>
<tr>
<th>Modulation</th>
<th>ø_mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>1.0</td>
</tr>
<tr>
<td>16QAM</td>
<td>0.8</td>
</tr>
<tr>
<td>QPSK</td>
<td>0.6</td>
</tr>
<tr>
<td>8PSK</td>
<td>0.6</td>
</tr>
</tbody>
</table>

1) Power allocation algorithm for 2*2 MIMO system

```
Initialize
P = P_i / P;
P_i_up = 1;
P_i_low = 1/N;
MI_P_i_pre = 0;

Repeat
Calculate F and MI_F
If P_i_up - P_i_low ≤ th1
   If MI_F > MI_P_i_pre
      P_i = (P_i + P_i_up) / 2
      P_i_low = P_i
      MI_P_i_pre = MI_F
   Else
      P_i = (P_i + P_i_low) / 2
      P_i_up = P_i
   End
Else
   Output = F and MI_F
End
Repeat until MI_F becomes maximum.
```
2) Power allocation algorithm for 3*3 MIMO systems.

**Initialization**
- \( P_1 = P_{1_{up}} + P_{1_{low}} \)
- \( P_{1_{up}} = 1 \)
- \( P_{1_{low}} = 1/N \)
- \( M_{F_{1_{low}}} = 0 \)

**Repeat**

1. Calculate \( F \) and \( M_{F} \)

2. **Loop 1:**
   - If \( P_{1_{up}} \leq \frac{P_{1_{low}}}{2} \)
     - If \( M_{F} \geq M_{F_{1_{low}}} \)
       - \( P_1 = \frac{P_{1_{up}} + P_{1_{low}}}{2} \)
       - \( P_{1_{low}} = P_1 \)
     - Else
       - \( P_1 = \frac{P_{1_{up}} - P_{1_{low}}}{2} \)
       - \( P_{1_{low}} = P_1 \)
     - \( M_{F_{1_{low}}} = 0 \)

   - Else
     - \( P_{1_{up}} = \min \{ P_{1_{up}} - P_{1_{low}} \} \)
     - \( P_{1_{low}} = \min \{ P_{1_{low}} - \frac{P_{1_{low}}}{2} \} \)
     - \( P_{1_{up}} = P_1 \)
     - \( P_{1_{low}} = P_1 \)
     - \( M_{F_{1_{low}}} = 0 \)

3. **Loop 2**
   - If \( P_{2_{up}} \geq \frac{P_{2_{low}}}{2} \)
     - Calculate \( F \) and \( M_{F} \)
     - If \( M_{F} \geq M_{F_{2_{low}}} \)
       - \( P_2 = \frac{P_{2_{up}} + P_{2_{low}}}{2} \)
       - \( P_{2_{low}} = P_2 \)
     - Else
       - \( P_2 = P_{2_{up}} \)
     - \( P_{2_{low}} = P_2 \)

   - Else
     - \( P_{2_{up}} = \min \{ P_{2_{up}} - P_{2_{low}} \} \)
     - \( P_{2_{low}} = \min \{ P_{2_{low}} - \frac{P_{2_{low}}}{2} \} \)
     - \( P_{2_{up}} = P_2 \)
     - \( P_{2_{low}} = P_2 \)

Repeat until \( M_{F} \) becomes maximum

**PERFORMANCE EVALUATION AND CONCLUSION**

In this simulation, codes are written in MATLAB version 2013. The simulation is performed for transmitters and receivers are 2 or 3. In addition, the channel characteristics are considered according to Chinese standard [3,4,5].

For this simulation, SNR is considered as [2]

\[
\text{SNR} = \frac{\text{Tr}(HH^H)}{N(\sigma_s^2 + \sigma_r^2)}
\]

Here, we demonstrated the mutual information values versus different values of impulsive index (A). From fig. 2, we observed that, when A is small, the mutual information value is high which is consistent with refs.[31, 33].

To verify the performance advantages of proposed precoding matrix (F), we compared the results with some basic precoding techniques like zero forcing precoding [12] and MMSE (minimum mean square error) precoding [13,14] for different SNR values and for different modulation schemes as shown in fig 3,4 and fig 5,6 for 2*2 and 3*3 MIMO port configuration respectively.

![Fig. 2 Mutual information vs. SNR (dB) with BPSK modulated transmitted signal for different impulsive index (A).](image)

![Fig. 3. Mutual information vs. SNR (dB) for 2*2 (MIMO) system with BPSK modulated transmitted signal for different precoding schemes with A=0.5.](image)

![Fig. 4. Mutual information vs. SNR (dB) for 2*2 (MIMO) system with QPSK modulated transmitted signal for different precoding schemes with A=0.5.](image)

![Fig. 5. Mutual information vs. SNR (dB) for 3*3 (MIMO) system with BPSK modulated transmitted signal for different precoding schemes with A=0.5.](image)
And even we can observe that, as the transmitter and receiver ports increases, the performance also increases in terms of mutual information value and thereby increasing the throughput as increasing the transmission rates as described in fig 7.

Also using higher modulation modes at different SNR, we can obtain the higher transmission rates at the transmitter. So that, for the given time-varying characteristics of PLC system, adaptive modulation is suitable for increasing spectral efficiency.

So, totally from all figures we observe the following:

1. The proposed scheme can achieve higher transmission rates compared to other schemes for moderate impulsive index value A (for moderate SNR).

2. As the number of transmitter and receiver ports increases, the proposed scheme gives better and better result.

3. Adopting higher modulation mode at transmitter, we can have better performance in terms of transmission rates.

4. With proposed algorithm, even though the threshold value is more, the performance of system does not degrade too much. And can achieve speedy operation with good accuracy.

Observing the tables 2 and 3, we can conclude that, the proposed policy for power allocation needs much less iterative numbers compared with the search method for described in [24] (water filling algorithm) especially when the port configuration is high with high modulation mode and with small step size.

### Table 2. Comparison of Speed and Accuracy for BPSK

<table>
<thead>
<tr>
<th>Specification</th>
<th>Threshold</th>
<th>Iteration Number</th>
<th>Maximum value of mutual information</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPSK</td>
<td>0.1</td>
<td>4</td>
<td>0.4582</td>
</tr>
<tr>
<td>Modulation 2*2 MIMO</td>
<td>0.2</td>
<td>3</td>
<td>0.4574</td>
</tr>
<tr>
<td>SNR=55 dB</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>5</td>
<td>0.5122</td>
</tr>
<tr>
<td></td>
<td>0.25</td>
<td>5</td>
<td>0.5042</td>
</tr>
</tbody>
</table>

### Table 3. Comparison of Speed and Accuracy for QPSK

<table>
<thead>
<tr>
<th>Specification</th>
<th>Threshold</th>
<th>Iteration Number</th>
<th>Maximum value of mutual information</th>
</tr>
</thead>
<tbody>
<tr>
<td>QPSK</td>
<td>0.1</td>
<td>5</td>
<td>0.5707</td>
</tr>
<tr>
<td>Modulation 2*2 MIMO</td>
<td>0.2</td>
<td>3</td>
<td>0.5197</td>
</tr>
<tr>
<td>A=0.5 SNR=55 dB</td>
<td>0.25</td>
<td>2</td>
<td>0.5170</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>12</td>
<td>0.6670</td>
</tr>
<tr>
<td></td>
<td>0.2</td>
<td>6</td>
<td>0.6554</td>
</tr>
</tbody>
</table>

REFERENCES


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