International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Achievable Throughput Optimization in Turbo Coded OFDM Systems and its Application to Power Line Networks

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Abstract: ***The aim of this paper is to study the bit-loading and power allocation problem in Turbo Coded Orthogonal Frequency Division Multiplexing (TC-OFDM) systems. The presence of interference (Inter-carrier Interference (ICI) and Inter-Symbol Interference (ISI)) significantly degrade the performance of TC-OFDM systems and make the resource management optimized without the assumption of interference is less efficient. To solve this problem, an initial solution based on the greedy approach is developed in this paper. Then, several reduced complexity approaches (RCA), which yield a little degradation compared to the initial solution, have been also developed. Then, a new algorithm based on static approach is also proposed in this paper, which has less complexity compared to the initial solution and also eliminate the interference ((ICI) and (ISI)) using adaptive filtering. Simulation results presented in the context of Power Line Communication (PLC) shows the comparison of OFDM systems with TC-OFDM systems, greedy with RCA, then performance of all these algorithms on TC-OFDM systems.***

Keywords: Bit-loading, power allocation, TC-OFDM, greedy algorithm, PLC.

1. Introduction

In the past decades, the use of PLC systems for high rate indoor broadband communications has spread rapidly [2]. Since PLC doesn’t require any new wire installation, it is economically attractive for indoor local area network (LAN). It can also be complementary with wireless LAN.

PLC systems exploit the OFDM technique to combat the effect of multi-path channels with severe frequency selectivity. The conventional OFDM divides the entire bandwidth into many orthogonal subcarriers and data are transmitted in parallel over these subcarriers. Therefore, it can support high transmission data rate and achieves high spectral efficiency. Unfortunately, many phenomena such as frequency offset between transmitter and receiver, insufficient guard interval or Doppler frequency shift, etc. induce inter-carrier interference (ICI) as well as inter-symbol interference (ISI) that significantly degrade the performance of OFDM systems and make the resource management more complicated. Many techniques have been developed to combat the effects of ISI and ICI, such as time domain windowing, frequency-domain equalization or ISI and ICI self-cancellation.

Both current and next generation of PLC systems employ frequency band from 2 to 30 MHz (and over), e.g., HPAV1, HPAV2, IEEE P1901, ITU-T G.9963. In this frequency band, many radio applications such as amateur radio, urgency and military services have already been exploited. To avoid interference with those systems, a spectral mask is specified for PLC systems. The IEEE P1901 standard uses the Windowed-OFDM instead of the conventional OFDM technique to adapt to the spectral mask. The Hermitian Symmetry Offset Quadrature Amplitude Modulation (HS-OQAM) is proposed for future use to increase the data rate as well as adapt to new spectral masks in Europe.

Regarding resource allocation, the bit-loading can be designed to achieve different objectives in OFDM systems, such as bit allocation, power allocation, code rate adaptation, etc. Different algorithms have been proposed among which we can enumerate: adaptive-rate algorithms which maximize the capacity under the power and bit-error rate constraints (BER); margin-adaptive algorithms which minimize the consumed power under data rate and BER constraints; BER minimization under data rate and power constraints. If the ISI and ICI are present, the system can be modeled as a Gaussian interference channel. In the absence of joint coding and decoding, the interference is considered as noise when solving the resource allocation problem. In [5] the achievable throughput of PLC systems is maximized by combining the bit-loading algorithm and adaptive cyclic prefix. The bit-loading algorithm used in [5] relies on two simplifying assumptions. First, the conventional OFDM is taken into account to calculate ISI and ICI in PLC systems while, as mentioned above, PLC systems exploit the Windowed-OFDM instead of the conventional OFDM. The second simplification is enabled by on/off power loading and integer bit number constraint. The latter leads to bit discretization that causes non optimal power use. Actually, the discretized bit-loading [12],[13] can be achieved with lower power consumption than with the approach in [5] and the residual power could be exploited to increase data rate or/and transmission quality. CP design for maximizing the achievable throughput for Windowed-OFDM systems is considered in [4]. Unfortunately, the power allocation strategy in [4] is also non optimal due to the bit discretization. In [5], [4], it is shown that the choice of a cyclic prefix (CP) length equal to the channel impulse response length makes PLC systems less efficient in terms of achievable throughput. Shorter CP evidently results in ISI and ICI, but the gain offered by shortened CP may exceed the losses caused by interference. Another approach to CP length adaptation relies on the statistical channel state information as derived in [6] [9]. This approach causes a capacity loss when compared to the bit and power allocation with the instantaneous channel state information (CSI) [7]. In our paper, we assume that perfect instantaneous CSI is available and we use it to optimize the resource allocation. Moreover, our interest is to optimize the throughput for fixed GI length and we take into account possible interference in the bit/power allocation [15]. Recently, several approaches to search for the upper-bound of the achievable throughput have been studied in [3] but no practical solution of the achievable throughput maximization problem with low-complexity has been given. A solution based on the greedy approach has been developed for the multi-carrier interference channel in multi-users ADSL systems. However, it only takes into account the ICI caused by the asynchronous cross-talk effect. Moreover, due to the difficulty to exact additional power computation, the algorithm in multiuser spectrum optimization for discrete multitone systems with asynchronous crosstalk exploits the gradient information to approximate the power adjustment when modifying the number of bits on subcarriers. The algorithm detailed in Multiuser spectrum optimization for discrete multitone systems with asynchronous crosstalk approximates the matrix inversion via power series expansion to reduce the complexity. This method works only if the assumption of convergence of the power series expansion is valid. In this paper, we focus on single-user Windowed-OFDM-based systems in the presence of ICI as well as ISI. However, a judicious iterative procedure for accurate matrix inversion calculation and an iterative bit-loading procedure exploiting the incremental power needed to transmit an additional bit are utilized instead of the approximations proposed in Multiuser spectrum optimization for discrete multitone systems with asynchronous crosstalk. In [1], greedy principle is used to solve the achievable throughput maximization problem in PLC systems in the presence of interference and under power and bit-error rate constraints. For this purpose, the ISI and ICI due to the presence of insufficient cyclic prefix in PLC systems have been analyzed. Relying on the ISI and ICI analysis and the greedy principle and an initial greedy algorithm is used to calculate the achievable throughput maximization in the presence of ISI and ICI. Then, several approaches are proposed in order to reduce the complexity with a negligible degradation compared to the initial greedy solution

2. Background

The various backgrounds behind this scheme are given below:-

2.1 OFDM Systems

Orthogonal frequency-division multiplexing (OFDM) is a method of encoding digital data on multiple carrier frequencies. OFDM has developed into a popular scheme for wideband digital communication. OFDM is a frequency division multiplexing (FDM) scheme used as a digital multi carrier modulation method. A large number of closely spaced orthogonal sub-carrier signals are used to carry data on several parallel data streams or channels. Each sub-carrier is modulated with a conventional modulation scheme (such as quadrature amplitude modulation or phase-shift keying) at a low symbol rate, maintaining total data rates similar to conventional single-carrier modulation schemes in the same bandwidth. The primary advantage of OFDM is to cope with severe channel conditions without complex eqalization filters

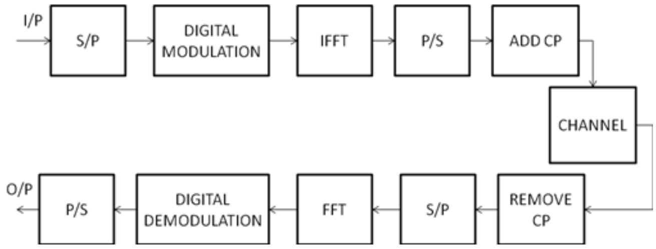

Figure 1: Block Diagram of OFDM System

The above figure shows the block diagram of the OFDM systems. The OFDM system basically involves transmission of a cyclic prefixed signal over a fading multipath channel. The input symbol denotes the transmission symbols/datas, for the k OFDM block. These symbols may come for instances from a M-QAM (M denotes the number of sub carries) then provided a serial to parallel converter. After serial to parallel conversion of the input symbol stream, each N parallel data streams are mapped to a symbol stream using digital modulation. An inverse FFT is computed on each symbol giving a set of complex time domain samples. After back parallel to serial conversion a cyclic redundancy of length is add as the cyclic prefix.The signal is then transmitted on a PLC channel. At the receiver we takes the FFT after the removal of CP

2.2 Turbo Coding

In 1993 Berrou, Glavieux and Thitimajshima proposed "a new class of convolution codes called turbo codes whose performance in terms of Bit Error Rate (BER) are close to the Shannon limit"[16]. The potential performance offered by turbo codes has excited both academic and industrial researchers. It is theoretically possible to approach the Shannon limit by using a block code with large block length or a convolutional code with a large constraint length. The processing power required to decode such long codes makes this approach impractical. Turbo codes overcome this limitation by using recursive coders and iterative soft decoders. The recursive coder makes convolutional codes with short constraint length appear to be block codes with a large block length, and the iterative soft decoder progressively improves the estimate of the received message.

2.2.1Turbo Encoding

Turbo code is the parallel concatenation of a number of RSC codes. Usually the number of codes is kept low, typically two, as the added performance of more codes is not justified by the added complexity and increased overhead. The input to the second decoder is an interleaved version of the systematic x, thus the outputs of coder 1 and coder 2 are time displaced codes generated from the same input sequence. The input sequence is only presented once at the output. The outputs of the two coders may be multiplexed into the stream. The interleaver design has a significant effect on code performance. A low weight code can produce poor error performance, so it is important that one or both of the coders produce codes with good weight. If an input sequence x produces a low weight output from coder 1, then the interleaved version of x needs to produce a code of good weight from coder 2.

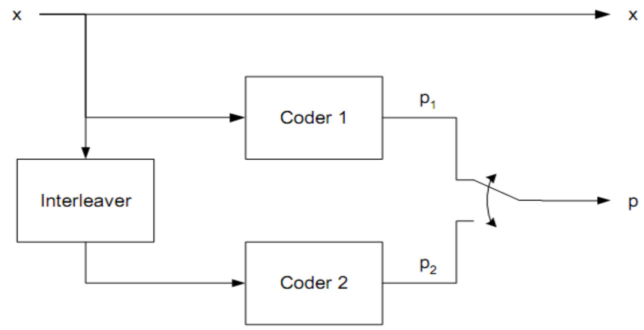

Figure 2: Turbo Encoder

Block interleavers give adequate performance, but pseudo random interleavers have been shown to give superior performance.

2.2.2Turbo Decoding

It is simplest to view the decoding process as 2 stages: initializing the decoder and decoding the sequence. The demodulator output contains the soft values of the sequence x' and the parity bits and . These are used to initialise the decoder, as shown in Figure3a. The interleaved sequence is sent to decoder 2, while the sequence derived from x' is sent to decoder 1 and presented to decoder 2 through an interleaver. This re-sequences bits from streams x' and so that bits generated from the same bit in x are presented simultaneously to decoder 2, whether from x, or .

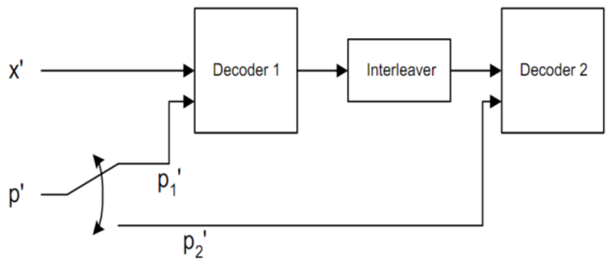

Figure 3a: Initialization

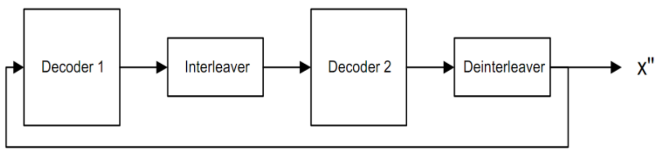

Figure 3b: Decoding

The decoder may have some knowledge the probability of the transmitted signal. This a priori information assists the decoder, which adds information gained from the decoding process forming the a posteriori output. The decoder uses all this information to make its best estimate of the received sequence. The output is then de-interleaved and presented back to decoder 1, which makes its best estimate. Further iterations through decoders 1 and 2, with associated interleaving and de-interleaving, refine the estimate until a final version of the block, x'', is presented at the output. This process is shown in Figure 3b.

2.3 PLC Channel Model

Power line can provide reasonably universal channels with simple and standard interface in the form of a wall socket plug [8]. The main disadvantages are limited bandwidth, high noise level, varying level of impedance attenuation and noise, etc.

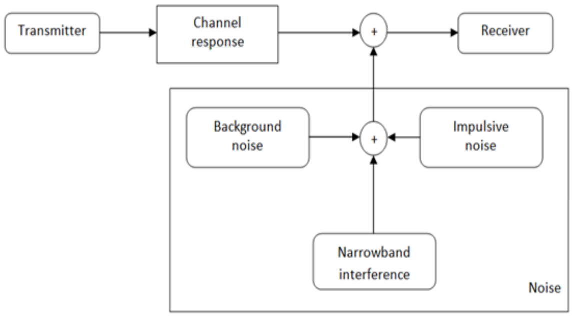

Figure 4: PLC Channel Model

Typically, many kinds of loads converted to the power line may act as noise sources. A High fluctuating noise levels and fluctuating impedance and transmission loss in power line may incur a considerable problem. Since power line is arranged in the power distribution circuits, transmission loss is inevitable. There are many channel models for the PLC channel. Any models cannot completely characterize the PLC channel because various kinds of channel impairment factors are involved in the PLC channel.

2.4 Greedy Algorithm

Let B, A, Q and C denote the bit-allocation vector, the allowable set of numbers of bits that correspond to available modulations on subcarriers, the objective function and the set of constraints (power constraints, data rate constraints, BER constraints). As Q and C depend on B, the corresponding optimization problem can be written as

$$A. \quad \varrho(B); B \in A^L, C \tag{1}$$

An algorithm is said to be greedy [1] if every decision taken at any stage is the one with the most obvious immediate advantage. That is to say it makes a locally optimal choice in the hope that successive choices will lead to a globally optimal solution. Generally, a greedy algorithm [11], [14]does not produce a global optimum, but nonetheless it may yield a local optimum that approximate well a global optimum.

3. System Model

Let us consider a Windowed-OFDM system with L subcarriers used out of M, which are activated under a given spectral mask constraint. The demodulated sample on the A. -th used subcarrier and A. -th OFDM symbol is given by

$$y(m_0, n_0) = \alpha(m_0, n_0) c_{m_0,n_0} + ICI(m_0, n_0) + ISI(m_0, n_0) + b(m_0, n_0) \quad (2)$$

where $\alpha(m_0, n_0)$, c_{m_0,n_0}, $ISI(m_0, n_0)$, $ICI(m_0, n_0)$ and $b(m_0, n_0)$ denote the channel multiplicative factor, the symbol of interest, the ISI and ICI coefficients and the complex circularly Gaussian noise sample at the m_0-th used subcarrier and n_0-th OFDM symbol. We assume that the channel is block-based time invariant. Without loss of generality and for the sake of simplicity, in a block of many OFDM symbols, Eq. (1) can be re-written as

$$y(m_0) = \alpha(m_0) c_{m_0} + ICI(m_0) + ISI(m_0) + b(m_0) \quad (3)$$

Since the number of subcarriers used in practical PLC systems is quite large, we assume that the interference on a given subcarrier is normally distributed (following the central limit theorem). Different normality tests for the interference have been introduced. These tests have confirmed the validity of Gaussian distribution of the interference in practical PLC systems. Then, the signal to interference plus noise ratio (SINR) and the theoretical capacity on the m_0th used subcarrier are given as follows:

$$SINR(m_0) = \frac{|\alpha(m_0)|^2 P(m_0)}{P_{ICI}(m_0) + P_{ISI}(m_0) + \sigma_b^2(m_0)} \quad (4)$$

$$C(m_0) = \log_2\left(1 + \frac{SINR(m_0)}{\Gamma}\right) \quad (5)$$

where P(m_0) is the power allocated to m_0-th used subcarrier and Γ is the SNR gap that models the practical modulation and coding scheme for a targeted symbol-error rate (SER):

$$\Gamma = \frac{1}{3}\left[Q^{-1}\left(\frac{SER}{4}\right)\right]^2 \quad (6)$$

where $Q^{-1}(x)$ is the inverse tail probability of the standard normalization distribution.

Let us denote A^{use} the set of used subcarriers, then #(A^{use}) =L, where # denotes the cardinality of A^{use}. On a given subcarrier, the interference power generally depends on the power allocated to other used subcarriers and can be written as

$$P_I(m_0) = P_{ICI}(m_0) + P_{ISI}(m_0) = \sum_{m=1}^{L} W(m_0, m) P(m) \quad (7)$$

where $W(m_0, m)$ is the interference contribution of the m-th used subcarrier on the m_0-th used subcarrier. In other words, $W(m_0, m)$ is the interference contribution of the m-th entry of A^{use} on the m_0-th entry of A^{use}.

Let W denote the interference matrix with entry (a, b) equal to $W(a, b)$ for a, b ∈ $\{1, \ldots\ldots, L\}$. Let P denote the allocated power vector and N the noise power vector. The total interference power and the SINR on the m_0-th used subcarrier are given by

$$P_I(m_0) = [WP](m_0) \quad (8)$$

$$SINR(m_0) = \frac{|\alpha(m_0)|^2 P(m_0)}{P_I(m_0) + N(m_0)} \quad (9)$$

4. Achievable Throughput in TC- OFDM

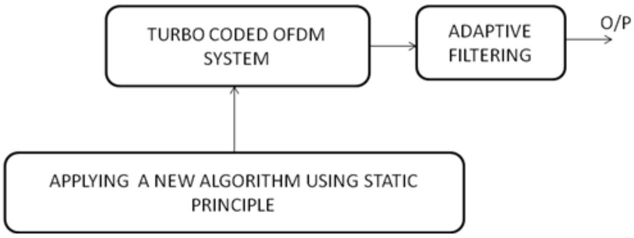

Figure 5: Block Diagram of Achievable Throughput optimization in TC-OFDM system

The above figure shows the throughput optimization in Turbo coded OFDM systems. Here we are applying a new algorithm based on static principle for bit allocation and then we will eliminate the interference completely by using the adaptive filtering. After this we will achieve the maximum throughput in TC-OFDM system.

4.1 Turbo Coded OFDM System

The combination of turbo codes with the OFDM transmission is so called Turbo Coded OFDM (TC-OFDM) can yield significant improvements in terms of lower energy needed to transmit data, a very improvement issue in personal communication devices. Unfortunately, the majority of existing papers treating the TC-OFDM assumes that the channel estimation using only the pilot symbols is sufficient (or even that the channel is perfectly known). It is shown, however, that there is a large potential gain in using the iterative property of turbo decoders where soft bit estimates are used together with the known pilot symbols. The performance of such an iterative estimation scheme proves to be of particular interest when the channel is strongly frequency- and time- selective.

Similar to every other communications scheme, coding can be employed to improve the performance of overall system. Several coding schemes, such as block codes, convolutional codes and turbo codes have been investigated within OFDM systems. Moreover, the deep fades in the frequency response of the channel cause some groups of subcarriers to be less reliable than other groups and hence cause bit errors to occur in bursts rather than, independently. The burst errors can extensively degrade the performance of coding. To solve this problem, several ways are considered. The easiest method is to use stronger codes, in fact an interleaving technique along with coding can guarantee the independence among errors by affecting randomly scattered errors. We use turbo code to improve the performance.

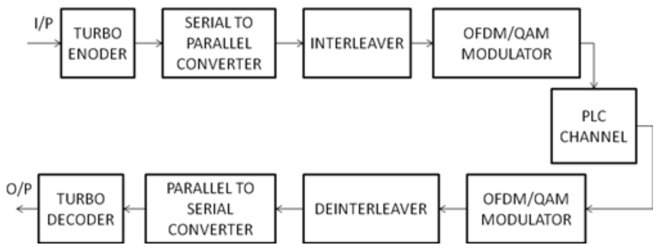

Figure 6 : Block Diagram of Turbo coded OFDM

Input data is given to the turbo encoder, where the turbo coding is done then transmit to the serial to parallel converters and then to the interleaver. After that data is given to an OFDM modulator where each N parallel data streams are mapped to a symbol stream using digital modulation. An inverse FFT is computed on each symbol giving a set of complex time domain samples. After back parallel to serial conversion a cyclic redundancy of length is add as the cyclic prefix. The signal is then transmitted on a PLC channel. At the receiver we take the FFT after the removal of CP then the reverse process will be carried out.

4.2 Adaptive Filtering

Adaptive filtering is a widespread technique in many applications. For acoustic echo cancellation (AEC) hands-free telephony, very large adaptive filters are used in a system identification context, whereas in digital communications, adaptive filters perform the channel distortion equalization. The present need for increased throughput in new systems also results in an increase of the equalizer length. In these two areas, there is a demand for efficient and low complexity algorithms. This paper builds on this approach. The least mean square (LMS) adaptive algorithm is widely used since it provides both low complexity and robust performance. However, the relatively slow convergence is a major drawback in several applications. This is the motivation for searching for improved, yet simple, versions of the initial algorithm. Interestingly, many solutions make use of projections of the input signal on an orthogonal basis, allowing them to act "almost" separately on the various modes of the convergence

4.3 Algorithm and Flow Chart of Achievable Throughput Optimization in TC-OFDM

Algorithm

- Take random samples of powers of 2 as a input sample signal
- Use turbo c codes for encoding the input sample signals
- Use the QAM for symbol mapper
- Take the IFFT of the signal for OFDM signal transmission for the input signal and assign the subcarriers
- Then allocate the bit for the each subcarrier using static policy that is predefined bit allocation
- Then transmit the OFDM symbol in the PLC channel which
- Then receive the signal then do the adaptive filtering then FFT for frequency domain to time domain
- Then do the demapping
- Then decoding using turbo decoder
- Then find the throughput for the TC-OFDM systems

5. Simulation Results

To verify the BER performance analysis, computer simulation was carried out. The figure below shows the performance of the OFDM system and the Turbo coded system. From the figure 8 it is clear that the performance of the Turbo coded OFDM system is very high that is the error is less than the OFDM

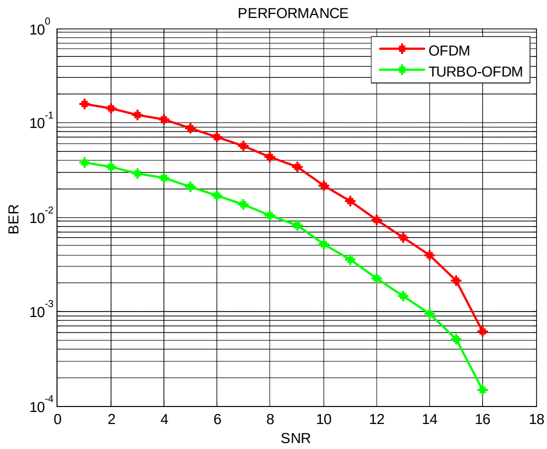

Figure 7: Performance comparison of OFDM and TC-OFDM

In our system we are removing the interference using the adaptive filtering. The performance of the turbo coded OFDM with interference and without interference is showing in the below figure

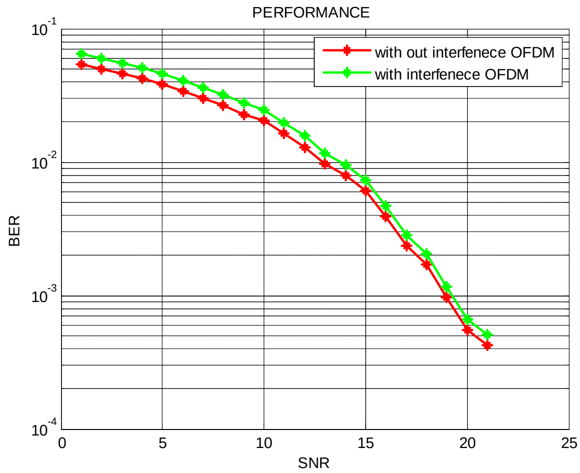

Figure 8 Performance comparison of TC-OFDM with and without interference

Now we illustrate the non-convex structure of the problem under study. The non-convexity has already been mentioned in [9]. To support this result, it is quite easy to find directions in the constrained power area where non-concavity arises.

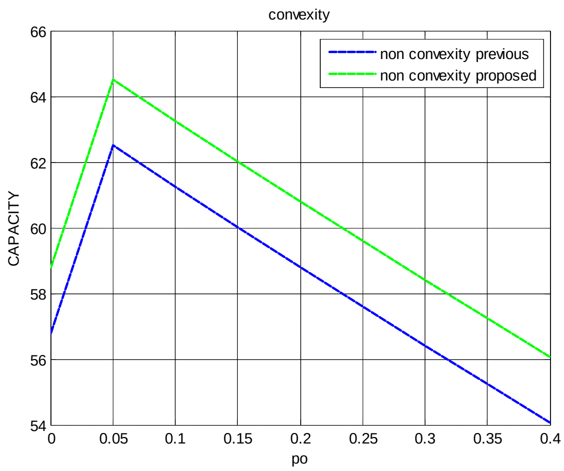

Figure 9 : An illustration of the prolem of concovexity

For instance, letting:

$$P(m) = \begin{cases} P_o & m \in [401{,}420 \\ 10^{-3} & m \in [1{,}400] \cap [421{,}91 \end{cases} \quad (11)$$

where linearly varies in from 0 to 0.4 (normalized to P_{mc}) yields non-concavity shape of C as in Fig.The figure above shows the non covexity problem of both OFDM and the TC-OFDM.

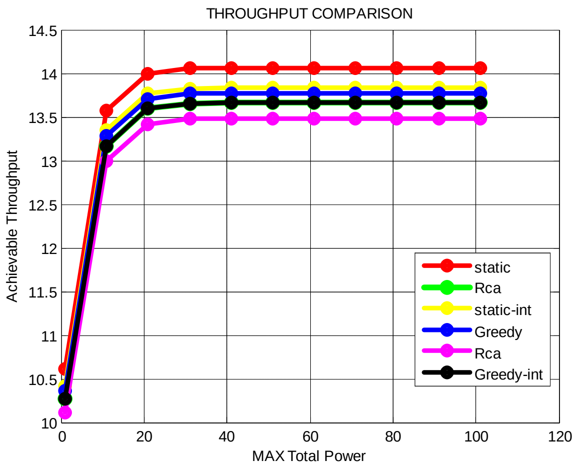

Figure 10: Throughput comparison for different algorithms

The figure 10 illustrate the Throughput achieved for different algorithms. From this figure it is clear that our new proposed algorithm i.e, static algorithm achieves the maximum throughput. Now we are initializing some cost function in static algorithm, that yields another algorithm know as the static-int. In our figure its clear that the existing RCA[1] will achieve less throughput than static and static-int algorithm. Throughput obtained for the OFDM using the existing greedy,greedy-int and RCA are less compared to the throughput obtained for TC-OFDM using our proposed algorithms.

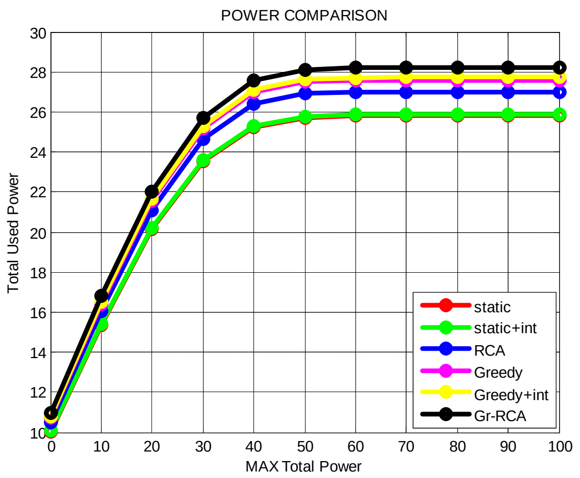

Figure 11: Power comparison for different algorithms

In the above figure it is evident that the power consumption of the existing algorithms i.e greedy,greedy-int and RCA is more than our proposed algorithms static and static-int. In our comparison it is clear that the total power used for the OFDM system using the these algorithms is more that our proposed TC-OFDM system.

The below figure 12 illustrate the complexity of different algorithms in TC-OFDM and the OFDM systems. Static,RCA and the static-int are applied to the TC-OFDM systems.

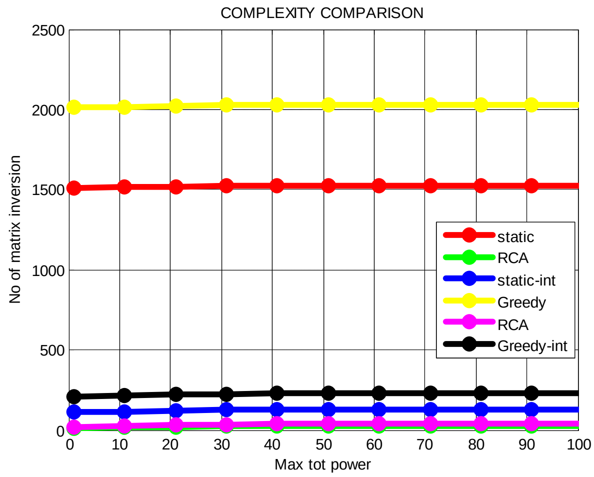

Figure 12:Complexity comparison for different algorithms

Among this static-int has the less complexity. Greedy, Greedy-int and RCA is applied to the OFDM system, among these RCA will have the less complexity

.

6. Conclusion

In this paper, new robust algorithms for the problem of achievable throughput maximization in PLC systems in the absence of interference have been devised. Instead of OFDM here we are using Turbo Coded OFDM systems. We have developed the static algorithms as well as static-int algorithm which have a reduced complexity. Simulation results have clearly shown that the proposed algorithms are efficient. The throughput achieved for static algorithm is more than the static-int but the complexity is significantly reduced for the staics-int. I have also simulated the total power used for different algorithms and from that it is evident that the power consumption of the existing algorithms i.e greedy,greedy-int and RCA is more than our proposed algorithms, static and static-int. In our comparison it is clear that the total power used for the OFDM system using the these algorithms is more that our proposed TC-OFDM.

7. Acknowledgments

I would like to thank Mr. Twinkle Bose and Adv. Dimple Bose for their valuable help for the successful completion of this paper and also for their comments, which enhanced the quality of this paper.

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