STM JOURNALS

International Journal of
Radio Frequency Innovations

Volume 1, Issue 1, 2023
Jan–June
DOI (Journal): 10.37591/IJRFI

https://journals.stmjournals.com/ijrfi

Research IJRFI

Mitigation of Peak to Average Power Ratio in Orthogonal Frequency Division Multiplexing through SOP-PTS

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Abstract

Orthogonal Frequency Division Multiplexing (OFDM) is a popular multicarrier modulation technology extensively employed in 4G wireless communication systems to transmit data over a dispersive channel. To address the Peak-to-Average Power Ratio (PAPR) issue in OFDM, a technique called Partial Transmit Sequence (PTS) is commonly utilized. The PTS method involves dividing the data block into non-overlapping sub-blocks and then combining them using phase factors to mitigate PAPR. However, the conventional PTS approach encounters a challenge as the number of sub-blocks increases, leading to exponentially growing search complexity due to the need to explore all possible phase factor combinations. To overcome this complexity and effectively reduce PAPR, a novel approach is proposed in this study, known as Particle Swarm Optimization (PSO)-based PTS technique. PSO is a bio-inspired algorithm capable of efficiently searching the solution space to find optimal solutions. By employing PSO, the proposed PSO-PTS method achieves a significant reduction in computational complexity, particularly for large sub-blocks, while obtaining lower PAPR levels. The simulation results demonstrate that the PSO-PTS approach outperforms the conventional PTS method.

Keywords: OFDM, PTS, Swam optimization algorithm, PAPR, digital radio transmissions.

INTRODUCTION

The primary telecommunications technologies, such as LANs, digital DTTs, and digital radio transmissions, heavily rely on a highly efficient modulation and multiplexing technology called Orthogonal Frequency Division Multiplexing (OFDM). Numerous references have described OFDM as a multi-carrier, multi-tone, and Fourier Transform technology [1]. The fundamental concept of OFDM involves transferring information across multiple carriers at a low rate. By carefully selecting the frequency spacing between carriers, they are made orthogonal, resulting in improved spectral efficiency and eliminating the need for steep band filters found in traditional single-carrier frequency division multiplexing. OFDM's key advantage lies in its ability to spread out frequency selective fading over multiple symbols [2]. This, along with the randomization of burst errors caused by fading and minimal signal modification, makes OFDM equalization easier to implement compared to single-carrier systems, thereby reducing the necessity for forward error correction. OFDM divides the signal into smaller sub-bands, ensuring that the frequency response across each sub-band remains relatively flat and smaller than the overall channel bandwidth. Successful signal transmission in OFDM relies on essential modulation and multiplexing techniques, which effectively reduce the effects of multipath fading, negating the need for complex equalization. Furthermore, as broadcast

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Received Date: September 22, 2023
Accepted Date: September 30, 2023
Published Date: December 1, 2023

Citation: K. Srinivasa Rao. Mitigation of Peak to Average Power Ratio in Orthogonal Frequency Division Multiplexing through SOP-PTS. International Journal of Radio Frequency Innovations. 2023; 1(1): 32–39p.

systems typically operate in a one-way direction, OFDM allows for higher spectral efficiency by controlling carrier strength and modulation for each carrier individually. The core principle of OFDM involves breaking down high-rate data streams into lower-rate streams and transmitting them simultaneously over multiple sub-carriers. Its multipath immunity enables the use of Single Frequency Network (SFN) transmission, which allows the same signal to be transmitted at the same time and frequency from multiple transmitters [3].

OFDM offers several advantages over conventional single-carrier methods, including the following: sub-carrier frequencies are chosen to be orthogonal across one OFDM period, allowing for digital modulation and multiplexing using the IFFT (Inverse Fast Fourier Transform) to create the required signals. The most significant advantage of OFDM over single-carrier systems is its ability to withstand all channel conditions without time domain equalization, making it less sensitive to sample timing offsets and having strong co-channel interference against narrow-bands. Overlapping sub-channels lead to resourceful utilization of the spectrum, and the channels are divided into flat-fading sub-channels, making OFDM more resistant to frequency-selective fading [4]. However, OFDM has some limitations: it has a noise-like amplitude, which necessitates RF power amplifiers with higher peak-to-average power ratios; it is more susceptible to carrier frequency offset and drift, as well as Doppler shift; it requires linear transmitter circuitry, which may result in poor power efficiency; and it is susceptible to efficacy loss due to cyclic prefix. The Peak-to-Average Power Ratio (PAPR) is a term that refers to the ratio between the sample's peak power and average power for a particular OFDM symbol. PAPR occurs when different sub-carriers in a multi-carrier system are out of phase, resulting in different PAPRs for various phase values. When all the points reach their maximum values at once, causing the output envelope to suddenly increase, this is known as the “peak” in the output envelope [5]. Multicarrier transmission methods have been developed to address OFDM's high PAPR. Although other techniques for reducing PAPR have been proposed, partial transmit sequence (PTS), clipping, and coding are the most commonly used. In order to prevent the supplied amplitude thresholds of the signals from being exceeded after corrections, amplitude peaks are corrected or signals are modified through clipping and filtering processes. The addition of corrective functions enables the correction of OFDM signals, limiting the signal s(t) to A0 at amplitude peak places. This method reduces interference of the OFDM signal with minimal power and prevents out-of-band interference. To reduce peak-to-average power ratio (PAPR), a code word is selected using coding techniques. However, lower coding rates result in lower bandwidth efficiency. Therefore, an optimum code must be determined, and lookup tables must be stored for decoding and encoding numerous subcarriers. Companding is a technique used to improve the efficiency of OFDM transmission by compressing and expanding digital signals before they are converted to analog waveforms. After taking the IFFT, OFDM signals are first combined and quantized, followed by D/A conversions, and then sent across the channel. Companding is particularly useful in voice processing or in situations where large peaks occur frequently. However, it also increases the quantization resolution of smaller signals while reducing the resolution of larger signals, resulting in increased PAPR at the expense of the system's bit error rate (BER) performance. The partial transmit sequence (PTS) method is an effective strategy since it maintains the number of subcarriers and has good PAPR reduction performance [7, 8].

The main aim of the PTS technique is to generate an optimal phase factor for a subset of smaller sub-blocks, aiming to minimize the Peak-to-Average Power Ratio (PAPR) in OFDM transmission. To achieve this, a rotating phase factor is applied to the input data, which has been divided into these sub-blocks. These modified sub-blocks are then combined to create the final OFDM transmission symbol. While PTS can be seen as a variation of the Selected Mapping (SLM) technique, it surpasses SLM in performance. Despite the significant PAPR reduction achieved by PTS, determining the ideal phase factors can be challenging. To address this, an optimization approach is employed to find the best phase parameters for PAPR reduction within the PTS framework. Particle Swarm Optimization (PSO) and genetic algorithms (GA) are the two most commonly used optimization techniques for this purpose. PSO is well-suited for solving problems involving nonlinear continuous optimization, whereas GA is inspired by natural selection and operates through random search . This research paper proposes the utilization of Particle Swarm Optimization (PSO) to determine the optimal phase factors for PTS. The paper discusses existing relevant works in literature in Section 2, outlines the procedures used in Section 3, and presents the experimental results in Section 4. Finally, the paper concludes with Section 5.

Related Work

Based on Massive Multiple-Input Multiple-Output (MIMO) downlink systems, Bao et al. [9] investigated the issue of Peak-to-Average Power Ratio (PAPR) in Orthogonal Frequency Division Multiplexing (OFDM). The hyper-parameters of the prior model were estimated concurrently with the signals using a Variational Expectation-Maximization (EM) technique. Furthermore, the Variational EM was coupled with Generalized Approximate Message Passing (GAMP), resulting in a significant reduction in the computing complexity of the proposed protocol. The final results demonstrated that the suggested protocol improved performance in terms of both PAPR reduction and computing complexity. Khyamet et al. [10] focused on two main problems: the signal's phases' placement and the availability of solutions. Two solutions to this issue were proposed. First, a narrowband Orthogonal Division Multiplexing (OFDM) signal was recommended, which could efficiently use the entire frequency system. Second, it was recommended to use an active optimization strategy to overcome the limitations of the localization protocol and ignore errors in the receivers' distance measurements for a single full cycle of the transmitted signal. he results of the studies show that the recommended system is less complex and more cost-effective than alternative conventional optical systems, while also possessing the precision required for higher accuracy applications. PSOA was used by Lye et al. [11] to distribute rates and subcarriers among several users. This method utilized the best solution for the least amount of transmission power and demonstrated great convergence. Additionally, the best allocation for the channel conditions could be employed at the cellular base station level. Sobhy et al. [12]. presented an analytical model for jitter-tolerant multi-channel filter bank OFDM receivers in. The authors have developed an optimization method for the filter bank bandwidth that can reduce the filter-bank order, preserving power and space while achieving the best signal quality. When using a second-order bandwidth-optimized filter bank that samples a 10 GHz OFDM signal with a tolerance of 6 ps of jitter, simulations showed that 34 dB and 38 dB SNR were achieved with five-channel and ten-channel receivers, respectively. Chen [13] suggested using the PTS approach to lower the PAPR of the OFDM signal. To lower the PAPR of an OFDM signal, a unique stochastic approach and an EM protocol were used. Results showed that, when compared to the stochastic method, the EM method achieved greater PAPR reduction with less computational complexity. In order to find the best phase rotation parameters and achieve a larger PAPR reduction, Bouhlel et al. [14] developed the PTS approach for Wavelet Orthogonal Frequency Division Multiplexing (WOFDM) based on Particle Swarm Optimization (PSO) [15]. It was observed that WOFDM performs better than regular OFDM at reducing PAPR. According to system evaluations, the proposed PTS-WOFDM method based on PSO-A improved the PAPR performance of conventional OFDM, PTS-WOFDM, PTS-OFDM, as well as PSO-based PTS-OFDM systems [16].

METHODOLOGY

In this section, PTS, Particle Swarm Optimization (PSO) methods are described.

Partial Transmit Sequence

PTS refers to a method for enhancing the statistics of multi-carrier signals. The fundamental concept behind PTS is the division of the original OFDM sequence into various sub sequences, and each subsequence is multiplied by various weights until an optimal value is selected. Figure 1 depicts the block diagram of the PTS method. Starting from the left side of the diagram, the data in the frequency domain, denoted as X, is split into V non-overlapping sub-blocks, and each sub-block vector has the same size of N. Each sub-block comprises N/V non-zero elements, and the remaining part is set to 0. It is assumed that the sub-blocks have equal size and no gap between them. The sub-block vector can be expressed as follows:

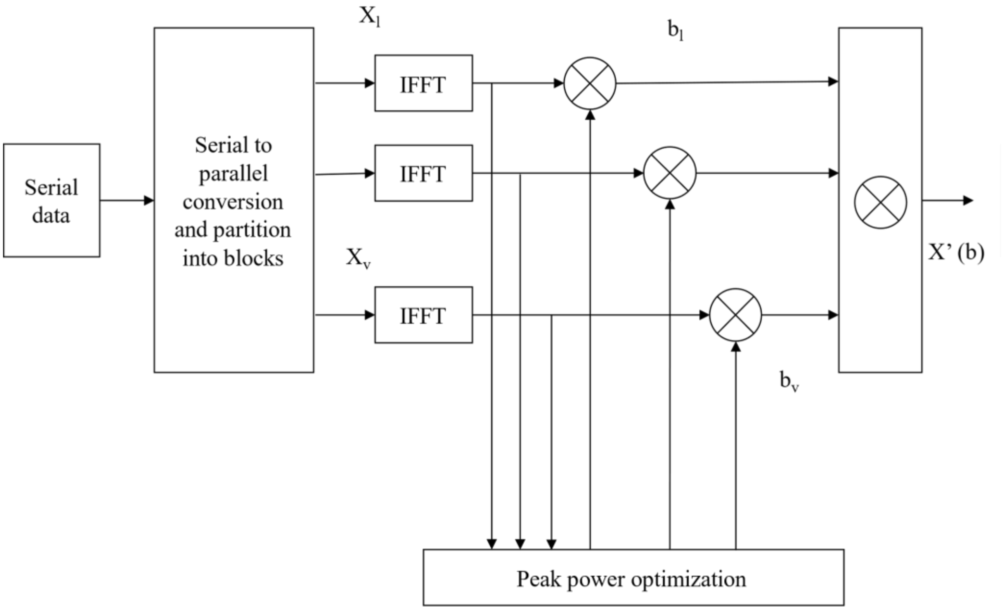

Figure 1. The block diagram of PTD technique with PSO optimization.

$$X = \sum_{v=1}^{V} b_v x_v \quad (1)$$

Where; $b_v = e^{j\phi_v}(\phi_v \epsilon [0,2\pi]\{v = 1,2, \ldots, x_v\}$

$$\hat{X} = IFFT(X) = \sum_{v=1}^{V} b_v X_v \quad (2)$$

For the optimal result 1 of the adequate factors from combination is chosen and the combination b = [$b1$, $b2$,…bv,] is expressed as

$$\text{b=[b1, b2, …, bv]}=argmin_{(b1,b2,\ldots,bv)}\left(max_{1\le n\le N}\left|\sum_{v=1}^{V} b_v X_v\right|^2\right) \quad (3)$$

The term “arg min [(•)]” refers to the condition that minimizes the output value of a function. The reduction of Peak-to-Average Power Ratio (PAPR) is directly proportional to the number of phase weighting factors used. If the number of phase weighting factors is large, finding the optimal combination of these factors will require exploring a large number of parallel addition processors and phase weighting factor sequences, leading to increased complexity in the system. PTS is a signal scrambling method that uses scrambling rotations on groups of sub-carriers in an OFDM system. Non-overlapping subsets of sub-carriers are formed, which are rotated independently and then combined to produce a signal with varying peak-to-average power ratios (PAPRs). The optimal subset with the minimum PAPR is selected, resulting in a reduction of the PAPR. The method can utilize the same amount of N-point IFFTs as the standard OFDM transform, provided that a large portion of the input values are 0. The method generates phase rotations, and the optimal subset with the lowest PAPR is selected. However, this method also has some issues, such as relatively higher computation complexity due to the search for an optimal sequence of rotation factors, and the requirement to transmit side information (SI) to receivers for undoing the rotations of OFDM sub-carriers. In PTS-OFDM systems, there are three sub-block partition strategies: adjacent, pseudo-random, and interleaved partitions. The adjacent partition strategy divides the sequence into V sub-blocks, each of which comprises N/V sequential sub-carriers. Traditional PTS uses the adjacent partition strategy (Singhal and Kumar 2014) [6]. In pseudorandom partitions, each sub-carrier can be arbitrarily assigned to positions of sub-blocks with length V. The common feature of the three distinct partition strategies is that each sub-carrier is assigned only once and the length of all sub-sequences is equal. In this strategy, the signal sub-bands are first divided into n sub-blocks using the pseudorandom partition strategy, and then the interleaved partition strategy is applied to the sub-blocks.

Utilizing the PTS method requires extensive exploration of viable phase factors to obtain optimum PAPR performance. Moreover, the computational load becomes impractical when the number of sub-blocks or phase factors is increased. Although several studies have focused on improving PAPR performance in OFDM systems, significant work has also been done to decrease the computation load of the PTS method. The extensive search complexity of the generic PTS method increases drastically with the number of sub-blocks, making it impractical for a large number of sub-blocks. Finding the best weighting factor is an NP-hard issue, and studies have investigated this issue using metaheuristic protocols. Among these protocols, swarm intelligence protocols are effective for lower computational complexity and rapid convergence. In this work, we investigate the Swarm Optimization based PTS to reduce the PAPR in OFDM [17].

PROPOSED PARTICLE SWARM OPTIMIZATION (PSO)

PSO depends on the exploration of search space to maximize or minimize a certain objective. The method is based on two ideas–swarm intelligence inspired on the swarm behavior of animals and the area of evolutionary computation [18]. PSO protocol optimizes many potential solutions in a given search space and in every iteration of the protocol the objective function which is being optimized is evaluated determining the fitness of the solution thus locating the maximum or minimum of the objective function.

In PSO scheme each particle have a position vector x and the solution is given in terms of W phase factor and V is moving velocity. For m dimensional optimization position and velocity of i^{th} particle may be given as [19],

$$W_i = \left(W_{i,1}\, W_{i,2} \dots\dots W_{i,m}\right) \text{ and } V_i = \left(V_{i,1}\, V_{i,2} \dots\dots V_{i,m}\right) \tag{4}$$

The two important factor here is defined $G_b = W_G$ and $P_b = W_{Pi}$, which represents the global best particle respectively. Individual best position depending upon best objective value.

$$W^G = W_{i,1}\, W_{i,2} \dots\dots W_{i,m} \text{ and } W^P{}_i = \left(W_{g,1}\, W_{g,2} \dots\dots W_{g,m}\right) \tag{5}$$

At time t+1 the new velocity $V_i(t+1)$ for particle i is updated by

$$V_i(t+1) = wV_i(t) + C_1 r_1\left(W^P{}_i(t) - W_i(t)\right) + C_2 r_2\left(W^G(t) - W_i(t)\right) \tag{6}$$

Wherein $V_i(t)$ is old velocity of particle i at time t. The C_1 and C_2 are called acceleration factor or rate to obtain best position and *w* is inertia factor. The new position of particle *i* is computed on basis of updated velocity by equation,

$$W_i(t+1) = W_i(t) + V_i(t+1) \tag{7}$$

On basis of performance evaluation of PAPR we can say that this sub optimal PTS scheme slightly degrades its performance to the conventional PTS. However, the computational complexity is very less as we have the threshold value for number of iterations.

The procedure of standard PSOA may be given by the following steps:

1. *Step 1.* Initialize a set of particles with arbitrary positions as well as velocities, wherein every particle comprises *K* variable.
2. *Step 2.* Assess the fitness value of every particle, assume *pbest* of every particle as well as its objective value is the same as the current position as well as objective value, and assume *gbest* as well as its objective value is the same as the position as well as objective value of the best initial particle.
3. *Step 3.* Update the velocity as well as position of all particles.
4. *Step 4.* Assess the objective value of every particle.
5. *Step 5.* For all particles, contrast current objective value with the object value of the *pbest*. If the current value is better, then update *pbest* as well as its objective value with the current position as well as objective value.

Furthermore, figure out the best particle of current swarm with the best objective value. If it is better than the object value of *gbest*, then update *gbest* as well as its objective value with the position as well as objective value of the current best particle.

The Methodology of Swarm Particle Optimization (SPO)

The steps for reduction of Peak-to-Average Power Ratio (PAPR) in Orthogonal Frequency Division Multiplexing (OFDM) systems can be summarized as follows:

1. *Initialization:* A number of particles are randomly generated in the search space and each particle is assigned a set of phase coefficients that correspond to the subcarriers in the OFDM system.
2. *Evaluation:* The PAPR of each particle is calculated using the assigned phase coefficients.
3. *Updating the velocity and position of particles:* The velocity and position of each particle are updated based on the particle's current position, its personal best position (the set of phase coefficients that give the lowest PAPR value that the particle has encountered so far), and the global best position (the set of phase coefficients that give the lowest PAPR value among all particles in the swarm). The velocity and position update equations are given by:

   $$v[i,t+1]= w_v[i,t] + c1 rand1 * (pbest[i] - x[i,t]) + c2*rand2 * (gbest - x[i,t])$$

   $$x[i,t+1] = x[i,t] + v[i,t+1] \tag{8}$$

   Where; w, c1, and c2 are the inertia weight, the cognitive weight, and the social weight, respectively, rand1 and rand2 are random numbers between 0 and 1, and x[i,t] and v[i,t] are the position and velocity of particle i at iteration t, respectively.
4. *Checking convergence:* The algorithm continues to update the velocity and position of particles until a stopping criterion is met, such as a maximum number of iterations or a satisfactory level of PAPR reduction.
5. *Output:* The global best position (the set of phase coefficients that give the lowest PAPR value among all particles in the swarm) is returned as the output of the SPO algorithm and can be used to reduce the PAPR in the OFDM system .

EXPERIMENTAL RESULTS

This work regards a QPSK-OFDM system with N =128 sub-carriers as well as 4 phase factors $\{1,-1, j,-j\}$ utilized for phase rotation on every sub block. A 10000 OFDM blocks are arbitrarily selected for simulation and set the oversampling factor L = 4 for choosing as well as predicting the signal with minimal PAPR. The 128 sub-carriers were split into 8 sub-blocks of 16 sub-carriers. The simulations are conducted using adjacent as well as random partitions as the sub block partitioning techniques for comparing the suggested technique with Gradient Descent and PSO-PTS.

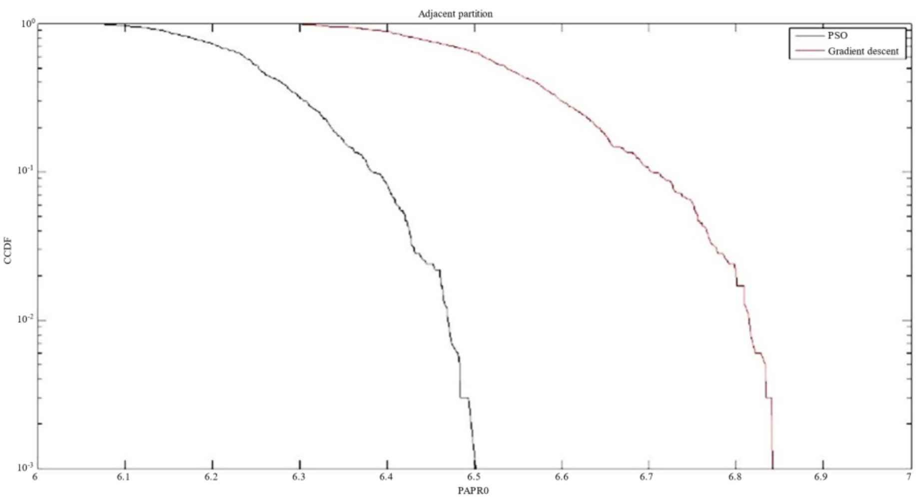

Figure 2. Comparison of the PAPR CCDF for adjacent partition.

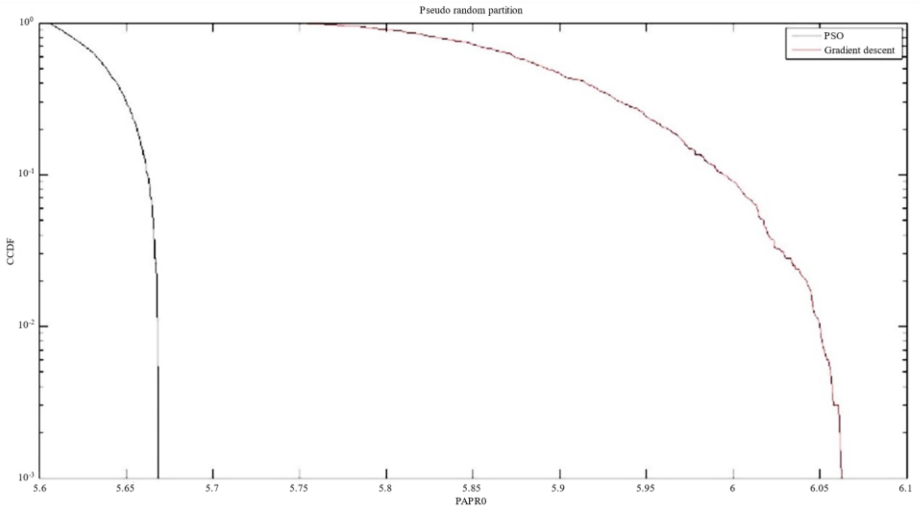

Figure 3. Comparison of the PAPR CCDF for random partition.

Figure 2 displays the CCDF curves of a QPSK-OFDM system of the PAPR for the proposed PSO-PTS and gradient descent for adjacent partition. The PAPR performance of the proposed PSO-PTS method is 0.5 dB better than gradient descent based on same computation load.

Figure 3 displays the CCDF curves of the 2 methods with arbitrary partition. The PAPR performance of the proposed PSO-PTS method is 1dB better than gradient descent based on same computation load.

CONCLUSION

PSOA is a highly effective method for optimizing challenging multi-dimensional problems with discontinuities across various domains. Its main objective is to locate areas of the highest particle concentration, even without any prior domain knowledge. The search initiates in random directions with arbitrary velocities to find particles. In this study, a new suboptimal approach called Particle Swarm Optimization with Phase Technique Search (PSO-PTS) is proposed for seeking improved combinations of phase factors. The simulations demonstrate that the PSO-PTS protocol is a powerful technique capable of achieving a significant reduction of 1 dB in Peak-to-Average Power Ratio (PAPR).

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