

# A Wind Driven Optimization Based WDM Channel Allocation Algorithm

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**ABSTRACT:** Nature-inspired algorithms are becoming powerful methods for solving many tough optimization problems. The performance of the system is significantly reduced which is due to the undesirable phenomenon that is Four wave mixing, a non-linear effect which becomes the main downside in optical communication systems. This crosstalk caused by four wave mixing can be decreased in WDM systems which have high capacity and do not use repeaters in the network by the utilization of an allocation technique that has been proposed in this paper, which comprises of channels that are unequally spaced in the system based on optimal Golomb ruler which permits the FWM reduction at the same time sustaining bandwidth efficiency. Both the systems employing equal and unequal channel spacing has been compared in order to attain affordable BER and Q-factor. The outcome of using this type of channel spacing is tested using OptSim. Simulations are presented to show the effectiveness of this technique in a 4-channel, 10-Gb/s per channel, system.

**KEYWORDS:** DWDM System, Four wave mixing, equal and unequal channel spacing, Golomb ruler algorithm, Wind driven Optimization.

## I. INTRODUCTION

Nature has the brilliant ability to optimize its elements which can motivate for creating various optimization methods that can be used to solve problems in engineering. The optimization process involves the exploration of the best values of parameters in a problem which are environment specified i.e. mainly it aims to search those values that qualify an objective function to produce the maximum or minimum value. In standard WDM systems, center frequencies which are equally spaced from each other determine the allocation of channels. Due to this, the noise (like FWM) has large possibility that they may enter into the equally spaced channels which results in severe crosstalk [1]. The crosstalk due to FWM proves to be the most serious limiting causes of performance degradation in optical systems employing WDM due to the fact that the lower input power in the optical systems are incorporated in this in contrast to other nonlinearities. To improve the performance, the FWM generation is avoided at the channel frequencies [1]–[7].

The crosstalk produced by FWM in optical systems is suppressed by using techniques of unequally spaced channel allocation (USCA) which are explored in [1], [8]–[14]. However, using unequal channel spacing increases the required bandwidth in contrast to equal spaced channel allocation (ESCA). This paper proposes an unequally spaced bandwidth channel allocation algorithm by considering the notion of optimal Golomb rulers (OGRs). These USCA methods to allocate channels decreases the FWM in optical communication systems effect resulting in the improvement of the performance of the WDM system without incorporating extra expense in terms of bandwidth [7], [15]–[17].

The exhaustive search [18]–[23] for higher order marks of such NP-complete problems is impossible. In searching for relatively suitable solutions to such NP-complete problems, various algorithms like Genetic Algorithm [24]–[28], and Firefly Algorithm (FA) [29] are quite successful and also offer a good initialization point for techniques of searching OGR sequences. Therefore, algorithms which are inspired by nature seem to be very successful solutions for the NP-complete problems. But in the set of nature-inspired algorithms, there is not a single algorithm which can stand out as the best for resolving every problem because every algorithm has its own strengths and weaknesses [30].

In the search for new methods, an innovative inspired by nature optimization technique called the Wind Driven Optimization (WDO) technique is proposed. In crux, the WDO is an iterative heuristic universal numerical

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optimization technique which is based on population for solving multi-dimensional and multi-modal problems with additional capability to instigate constraints on the search space.

The content of remaining sections is mentioned as follows: a brief work related to the algorithm is presented in section II, a brief concept of Golomb rulers is exhibited in section III, the proposed WDO algorithm on which allocation of channels is based shown in section IV. Section V gives the simulation results comparing equal and unequal channel spacing. Section VI presents some concluding remarks.

## II. RELATED WORK

The Golomb Ruler sequences can be generated using various techniques which can be classical methods, soft computing approaches and nature-inspired algorithms. The classical methods include Extended Quadratic Congruence (EQC) and Search Algorithm (SA) while soft computing approaches comprise Genetic Algorithm (GA), Biogeography Based optimization (BBO). The nature-inspired techniques involve Firefly Algorithm (FA), Bat Algorithm (BA), etc. But as the algorithms are based on different approaches there is no single algorithm which can be applied to all the problems. Therefore, all these algorithms are application specific which we can apply based on the optimization problem in hand.

## III. GOLOMB RULER

The phrase “Golomb ruler” [31] denotes a set of positive integer values, where any two numbers from the set consisting of different pairs do not have the same difference. Theoretically, this is identical to a ruler formed in a way where any two pairs of marks do not calculate the same distance. An illustration of the Golomb ruler is displayed in Figure 1. An Optimal Golomb Ruler depends on given number of marks and is the shortest ruler possible [32]. For allocating channels in WDM system, it is feasible to attain the least distinct number by applying Optimal Golomb Ruler to the channel allocation problem. The new FWM frequencies produced will not lie in the one previously allocated for the channels due to the fact that any two numbers taken as a pair do not have the same distance.

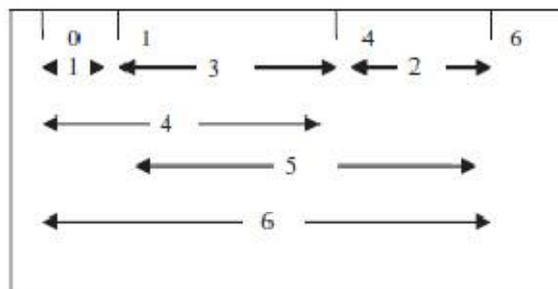


Figure 1: A perfect Golomb ruler with length 6.

An illustration of 4-marks Golomb ruler is displayed in Figure 1 with the distance related with each pair of marks [24]. The ruler length of Golomb ruler shown in Figure 1 is 6 and it also measures all the integer distances from 1 to 6 (and is therefore also a perfect ruler) [24], [33]-[37].

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## IV. WIND DRIVEN OPTIMIZATION TECHNIQUE

To generate OGRs, a novel optimization nature-inspired metaheuristic algorithm called WDO is being proposed in this paper. The wind blows to balance the air pressure in our atmosphere which means it gusts from a high pressure region to a low pressure region with a speed that is relative to the pressure gradient [38, 39]. Taking assumptions of hydrostatic air balance and vertical movement is weaker than the horizontal movement, the change in pressure as well as the motion of wind can be taken as a horizontal movement [39]. Although, our world is a three-dimensional, the motion of wind takes into account addresses multi-dimensional problems. Furthermore, to derive the operators employed in WDO algorithm, specific assumptions and simplifications are required. The algorithm initializes with Newton's second law of motion that offers very precise results when utilized to analyze the motion of wind [40, 41]:

$$\rho a = \sum F_i \quad (1)$$

where, the air density is denoted by  $\rho$ ,  $a$  denotes the acceleration vector, and the forces acting on the mass are denoted by  $F_i$ . The relation between air pressure, density and temperature is given by:

$$P = \rho RT \quad (2)$$

Where pressure is denoted by  $P$ , universal gas constant is denoted by  $R$  and temperature is denoted by  $T$ .

The equation (1) specifies that the motion of wind in a specific direction or path is controlled by four main forces in which the most dominant force that makes the movement of air is the pressure gradient force ( $F_{PG}$ ), whereas the friction force ( $F_F$ ) opposes such movement. The definition of friction force is given by equation (6). Gravitational force ( $F_G$ ) acts as an important force that pulls the particles in the direction of the origin of the coordinate system. Another force which happens due to rotation of earth and causes the movement of wind from one dimension to another is the Coriolis force ( $F_C$ ). The implementation of WDO as the movement in one dimension influences the speed in another.

The equations by which these forces are defined are given below, where  $\delta V$  denotes an infinitesimal air volume. Rotation of the earth is represented as  $\Omega$  represents the, gravitational acceleration is denoted by  $g$ , and velocity vector of the wind is denoted by  $u$ .

$$F_F = -\rho \alpha u \quad (3)$$

$$F_G = \rho \delta V g \quad (4)$$

$$F_C = -2\Omega \times u \quad (5)$$

$$F_{PG} = -\nabla P \delta V \quad (6)$$

All the above equations defining forces may be added up and put in the right-hand side of the Newton's second law of motion. The equation formed is given below:

$$\rho \Delta u = (\rho \delta V g) + (-\nabla P \delta V) + (-\rho \alpha u) + (-2\Omega \times u) \quad (7)$$

The velocity update equation can be derived from the above equation by considering an infinitesimal air particle that moves with the wind. The pressure in equation (2) can be substituted in place of  $\rho$  and an assumption of time step to be unity ( $\Delta t = 1$ ) is taken which gives the velocity update equation:

$$u_{new} = (1 - \alpha)u_{cur} - gx_{cur} + \left( \frac{RT}{P_{cur}} |P_{opt} - P_{cur}| (x_{opt} - x_{cur}) \right) + \left( \frac{cu_{cur}^{other \ dim}}{P_{cur}} \right) \quad (8)$$

The updating of the location of air parcels and their velocity is done in each iteration which is done by using equation (8) whereas updating their position is done by employing the below equation:

$$x_{new} = x_{cur} + (u_{new} \Delta t) \quad (9)$$

### 4.1 Generation of near-optimal Golomb ruler sequences using WDO Algorithm

To produce near-optimal Golomb ruler sequences, the pseudo-code for WDO Algorithm proposed in this paper is shown in Figure 2.

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## Wind Driven Optimization to Generate OGRs

### Begin

/\* WDO parameter initialization \*/

Channels (marks) 'n' initialization and set upper bound on the ruler length

**While** not *Popsize* /\* User defined size of population\*/

Define Pressure function, coefficients and boundaries;

Generate initial random population and velocity of air parcels;

Check Golombness of each air parcel;

**If** Golombness is satisfied

Keep that individual;

**Else**

Delete that specific air parcel from the generated population;

**End if**

**End while**

/\* End of WDO parameter initialization \*/

Evaluate initial population;

Find best air parcel in the initial population;

**While** not *S* /\* S is a stopping criterion \*/

Get an air parcel velocity randomly;

Evaluate its pressure (fitness);

Update velocity and check velocity limits;

Update position and check position limits;

**A:** Recheck Golombness of new air parcels;

**If** Golombness is satisfied

Keep that air parcel and then go to B;

**End if**

Delete that particular air parcel from the population;

Generate a new air parcel and then go to A;

**B:** Recompute the pressure (fitness) value of the modified air parcels;

Sort the population from best to worst based on pressure values (fitness);

Replace the Global pressure values with the best;

Keep the best solutions;

Solutions are ranked and best solution currently is found;

**End while**

**End**

Figure 2: Pseudo-code for WDO Algorithm to produce near-optimal Golomb ruler sequences.

All the steps to generate Golomb ruler sequences from WDO algorithm is given in Figure 2. The steps initiate from initialization of parameters and end at checking Golombness and raking the population from best to worst.

## V. SIMULATION RESULTS AND DISCUSSION

To produce Optimal Golomb Ruler (OGR) sequences, Wind Driven Optimization algorithm is applied. This method to produce near-OGR sequences have been devised and verified in MATLAB-7.12.0.635 (R2011a) in Windows 8, 64-bit operating system. It has been executed on Intel Pentium(R) Dual-Core CPU T4400 @ 2.20 Ghz processor laptop with 2 GB RAM.

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## 5.1 Simulation parameters for WDO

To obtain near-optimal sequences after a set of thorough experimentation, subsequent optimum WDO parameters have been established as shown in Table 1. The RT coefficient, Gravitational constant and Coriolis Effect is chosen to provide optimum efficiency.

Table 1: Simulation Parameters for WDO algorithm

Parameter	Value
Number of Air Parcels (Popsiz)	30
RT Coefficient ( <i>RT</i> )	3
Gravitational Constant ( <i>g</i> )	0.2
Coriolis Effect ( <i>c</i> )	0.4
Constant in the Update Equation ( <i>α</i> )	0.4
Maximum Allowed Speed	0.3
Maximum Iterations	1000

With these parameters configuration, a number of trials for different marks were done. A collection of 10 trials for n = 4 to 6 are shown in Table 2. All the sets perform similar as shown in Table 2.

Table 2: Performance of WDO for Different Marks in a Set of 10 Trials

Trials	n = 4		n = 5		n = 6	
	Ruler Length	Total Bandwidth (Hz)	Ruler Length	Total Bandwidth (Hz)	Ruler Length	Total Bandwidth (Hz)
1	6	11	11	23	18	45
2	6	11	12	24	17	44
3	6	11	12	24	17	45
4	7	11	11	24	18	43
5	6	11	11	23	18	43
6	6	11	11	23	17	44
7	6	11	12	23	17	43
8	7	11	11	24	17	44
9	6	11	12	23	18	44
10	7	11	12	24	18	43
Optimal Ruler Length = 6 Optimal Total Bandwidth = 11 Hz		Optimal Ruler Length = 11 Optimal Total Bandwidth = 23 Hz		Optimal Ruler Length = 17 Optimal Total Bandwidth = 43 Hz		

## 5.2 SIMULATION SETUP OF EQUAL AND UNEQUAL CHANNEL SPACING

The simulation arrangement to estimate the influence of changing spacing between input channels in a DWDM system in presence of FWM is displayed in Figure 3 consisting of four Continuous Wave lasers which are modulated by 10 Gbps NRZ data externally with channel spacing of 0.2 nm for equal spacing.

The results are measured for an optical span of 50 km of 0.25 dB/km attenuation factor and fiber. A BER tester is placed to evaluate the eye diagram at the receiver output.

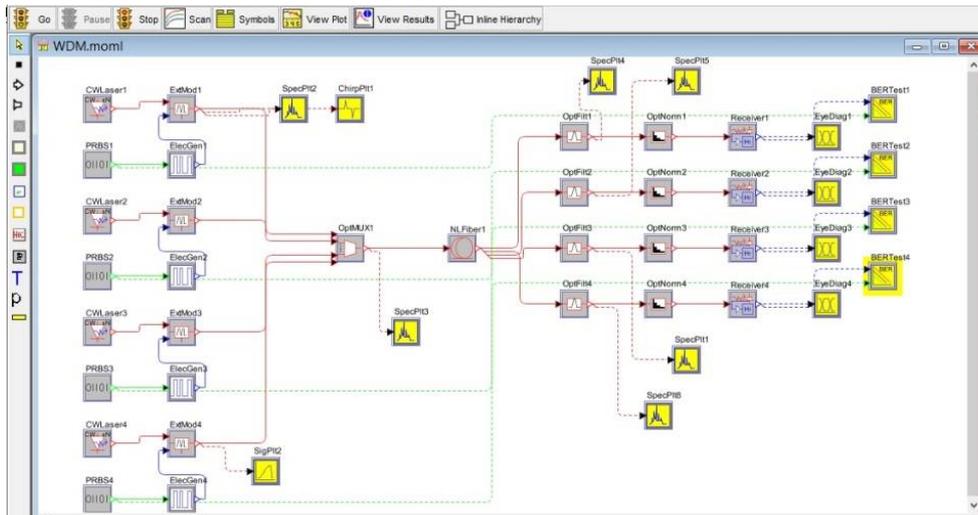


Figure 3: Simulation setup of DWDM system

In Figure 4, the outcome of a 4-channel DWDM system is shown in the form of eye diagrams with channel spaced equally with 0.2 nm spacing whereas Figure 5 shows the 4-channel DWDM system with the spacing of channels defined by the use of Golomb rulers i.e. unequal channel spacing.

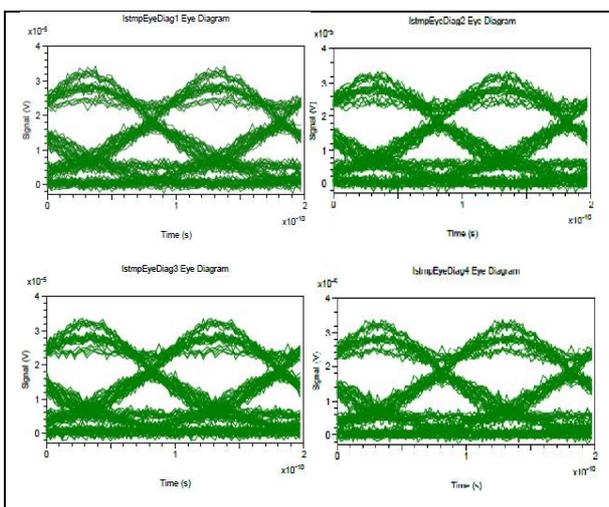


Figure 4: DWDM system Eye diagrams employing equal spacing between channels.

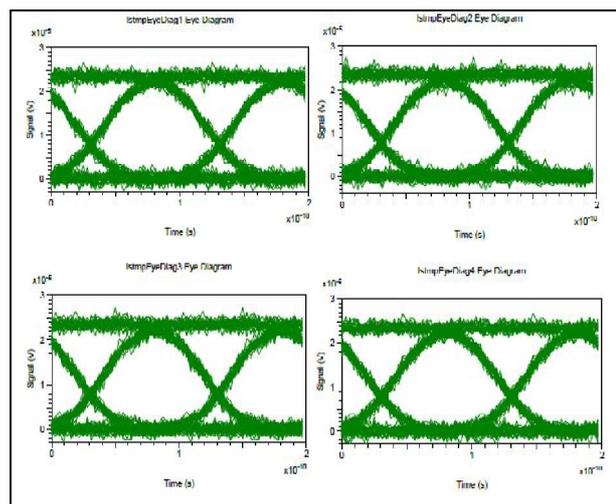


Figure 5: DWDM system eye diagrams employing unequal spacing between channels.

It can be seen that the performance of WDM systems employing Golomb rulers for channel spacing is superior to the channels employing equal spacing. We have measured bit error rate for the same construction of channels with equal and unequal spacing. It is revealed in the simulation that the system employing unequal spacing between channels improved the Q factor for DWDM systems as shown in Tables 3 and 4.

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Table 3: BER and Q factor for equal channel spacing in the given DWDM system

Channel Frequency (nm)	BER	Q (dB)
1550	1.9424e-011	1.6402e+001
1550.20	2.0546e-011	1.6391e+001
1550.40	2.2248e-011	1.6375e+001
1550.60	2.5439e-011	1.6349e+001

Table 4: BER and Q factor for unequal channel spacing in the given DWDM system

Channel Frequency (nm)	BER	Q (dB)
1550	6.9988e-031	2.1210e+001
1550.20	8.2000e-031	2.1200e+001
1550.45	9.4653e-031	2.1190e+001
1550.75	1.0334e-030	2.1185e+001

## VI. CONCLUSION

In this paper, we have formulated the function of a novel metaheuristic nature-inspired WDO to solve the highly complex problem of optimal Golomb ruler sequences. It has been seen that the proposed metaheuristic algorithm generates OGR sequences with high efficiency and effectiveness. An implementation of DWDM system has been studied to evaluate Q factor and BER with FWM present in the system. The system is designed under consideration of channels with equal and unequal spacing. It has been realized that using unequal channel spacing increases the required bandwidth in contrast to equal spaced channel allocation. Our outcomes after simulations provide a proficient method of utilizing Golomb rulers for allocating channels with unequal spacing resulting in the improvement of the performance of the WDM system without incorporating extra cost in terms of bandwidth and also results in decrease in FWM effect.

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