IJCSE International Journal of Computer Sciences and Engineering Open Access
Research Paper Vol.-7, Issue-5, May 2019 E-ISSN: 2347-2693

System Performance of De-MZM Employed Radio over Fibre System Using PSO Algorithm

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DOI: https://doi.org/10.26438/ijcse/v7i5.98104 | Available online at: www.ijcseonline.org

Accepted: 12/May/2019, Published: 31/May/2019

Abstract— In this paper, Particle Swarm Optimization, a nature-based algorithm is executed on the radio over fibre system. Phase noises which generate on the transmitter side of a communication system are eliminated by optimising the values of linewidths of the laser diode and RF Oscillator. Carrier to Noise ratio is considered as the main parameter and it is optimized with reference to a predefined level of 28dB. The practical ranges of 100 to 624 MHz and 0.1 to 10 Hz are taken into account for linewidths of the Laser Diode and Radio Frequency oscillator respectively. The changes in the optimised values are observed in the fibre of 2 Km, 10 Km and 30 Km. The optimum value of linewidth is calculated to be around 0.1 Hz for RF Oscillator and 500 MHz for the laser diode. The noise keeps on increasing with the increase in the length of fibre and PSO has been used to counter the phase noises by optimising the linewidth values.

Keywords— RoF-Radio over Fiber, SSMF-Single Standard Mode Fiber, MZM-Mach Zehnder Modulator, CNR-Carrier to Noise Ratio, OSSB-Optical Single Sideband Signal, CS-Central Station, BS-Base Station, PSO-particle swarm optimization, pbest- personal best, gbest-global best.

I. INTRODUCTION

The communication and technology when embedded together has proved to be a very significant field since the advent of Morse code in the year 1836. Starting from the invention of electric phone to the recent time invention of face time, the qualitative innovations have somersaulted the very face of communication in merely few decades. All the functions related to the communicating from one place to another or multipoint. communication have few underlying qualitative factors such as the medium of communication, noise, attenuation, Carrier to noise ratio etc. The optical fibre has bought a revolution in the communication field providing the highest bit rate and speed simultaneously. Radio over fibre is a such invention which has the qualities of both the wired and wireless communicationembedded in it, providing easy access and low noise in a single package [1]. Various advantages of radio over fibre includes the availability of signals of high quality, low fibre attenuation of 0.2 dB/Km, improved coverage, enlarged capacity, multi-transmission on a single fibre and meagre electromagnetic interference.

The broad applications of this technology include picocellular network architectures, mobile communication, Multipoint Video Distribution Services (MVDS), fibre to home services, RoF technology in fixed and MIMO networks [2]. Radio over fibre system communicates between BS and CS through a single optical fibre. So far this is being done by components like LD, RF oscillator and MZM on the transmission side and photodetector and filter on the receiving end, while both the ends are connected through SSMF fibre.

II. RELATED WORK

In the year 2001, the effect of optical crosstalk in these systems which have Wavelength Division Multiplexing incorporated in the system were investigated. The resultant effect of radio frequency carrier phase on penalty of optical fibre has been taken in account and further it was proved that the appropriate electrical frequency assignment can virtually eliminate the impact of optical crosstalk due to adjacent optical channels [3]. In 2005, phase noises obtained from the oscillator and the laser diode were mathematically discussed along with the PSD function. OSSB signal has an advantage of high tolerance towards power deterioration because of chromatic dispersion, thus, Mach Zehnder modulator was deployed to generate this kind of signal to be transmitted on the optical fibre. Carrier to noise ratio obtained at the receiver end was found to be more sensitive towards radio frequency oscillator rather than towards the laser. Fibre chromatic dispersion and power deterioration has a great negative influence on CNR penalty quantitatively and qualitatively [4]. Millimetre wave and microwave signals can be effectively transmitted through radio over fibre. So, the use of this technology becomes inevitable in wireless communication when these wave bands are involved. The signals ranging from few gigahertz up to 60 GHz have been used for experimentation in different generation technologies [6].

Nature-based algorithms have gained quite a popularity in the field of technology from the last few decades. One such algorithm has been used in this paper. Particle Swarm Optimization which uses the natural phenomenon of birds in swarms searching their food has been used to optimize varied solutions. PSO was developed in 1995 in the United States by Dr Eberhart and Dr Kennedy. It is an optimization technique based on stochastic population. The reason for considering PSO owes to easy implementation, fewer parameters and accurate results. Till date, this algorithm has been implemented in various areas like fuzzy systems, artificial networks, electrical loss adjustment etc. In this paper, PSO has been applied to Radio over Fiber system, so as to obtain an optimum value of Carrier to Noise ratio along with the percentage of received power at varied lengths of fibre. In this paper, RoF system is considered and particle swarm optimization is applied on it in order to obtain an optimized CNR penalty value and bandwidth value at a different number of iterations when the length of the optical fibre is taken to be 10 km.

III. THEORY

On the transmitter side, a laser diode is used for generating continuous wave signal, further it is externally modulated using dual electrode Mach Zehnder Modulator (DE-MZM) with a high-performance advantage over direct detection techniques. The signal reaccepted from the antenna or the actual data is provided by RF oscillator [11].

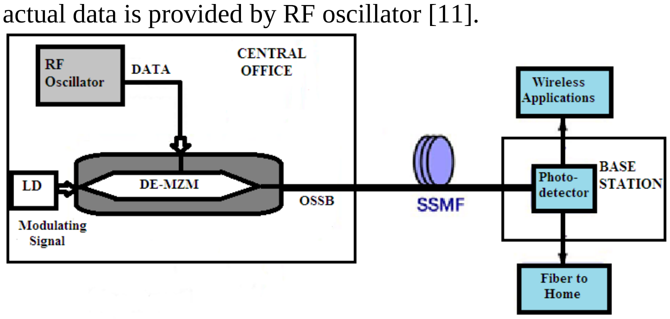


Fig.1. The architecture of Radio over Fiber system

In this, electrical to optical conversion of the data takes place. The usual ODSB can extensively degrade the signal, so the OSSB signal is generated using DE-MZM and phase shifter. The output obtained is given by equation (1).

$$E_2(t) = \frac{1}{2}\left[e^{j}\left(\frac{\pi V_{DC1}}{V_{pi}}+\frac{\pi V_1(t)}{V_{pi}}\right)+e^{j}\left(\frac{\pi V_{DC2}}{V_{pi}}+\frac{\pi V_2(t)}{V_{pi}}\right)\right]\sqrt{2P_i}e^{j\omega_c}t \quad (1)$$

where, ω_c is the frequency of optical carrier, V_{pi} is the voltage to switch MZM and P_i is the output power feeding the MZM. The signal after conversion is transmitted over a media of optical fiber. SSMF fiber is employed as it provides least chromatic dispersion, which degrades the signal under the acceptable levels. As shown in Fig. 1 on the receiver side, photo detector is used for detection purposes. In this work direct detection is used as it provides a cost effective solution [3]. Square law detection is used in photo detection scheme where the current is directly proportional to the optical signal generated as written in equation (2).

$$I(t)=[E_s(l,t)]^2 \quad (2)$$

Where, $E_s(l,t)$ is the input signal accepted by photodetector, generated by DE-MZM and transmitted over l Km of fiber. Particle swarm optimization based approach is deployed in this paper. It is a type of nature based algorithm extracted from the patterns in which birds fly in a group and without any obstruction or hindrance amongst the group they are able to locate the food precisely. In this we have few terms like pbest and gbest which defines the personal best of a bird and global best of bird. Each bird is referred to as a particle and the particles own best position is said to be it's pbest and the best position amongst all the particles is said to be the gbest. In this paper, the linewidth of a laser diode ($£_{LD}$) and linewidth of RF oscillator ($£_{RF}$) are taken under consideration. The particle swarm optimization is applied to these ranges such that one can obtain the precise values of these both factors in conjunction with the absolute value of Carrier to Noise ratio.

IV. METHODOLOGY

In our simulation setup first RoF system is mathematically modelled in terms of the carrier to noise ratio, the linewidth of RF oscillator and linewidth of the laser diode. Here a signal of 30 GHz is transmitted using a 1550 nm laser diode. While transmitting the signal over optical fibre additional losses of 0.5dB/km are taken under consideration and length of fibre used is 2 Km, 10 Km and 30 Km respectively. Fibre attenuation is also taken into account with a value of 0.20 dB/km. Other parameters considered are elaborated in table 1.1. After the system is created, nature-based algorithm particle swarm optimization is deployed for finding the accurate value of linewidth of RF oscillator and laser diode within the predefined ranges.

Table 1 Simulation parameters.

Parameter	Value
Attenuation, α_{fiber}	0.20 dB/km[1]
Responsitvity,r	1A/W[2]
Wavelength,λ	1550nm
Frequency of RF oscillator, $f_{oscillator}$	40GHz
Half power bandwidth,p	0.5[tae sik Cho]
Additional losses, L_{add}	0.5dB/km[2]
Fiber dispersion parameter,Dis	17ps/nm.km
Length of the fibre, L_{fiber}	2km to 30 km

IV.I Mathematical modelling of Radio over Fiber system in terms of its CNR

As shown in the figure above the input to laser diode is RF oscillator and the signal from the receiver antenna. In this paper, the work is mainly focused on the linewidths of RF Oscillator and LD. Varied parameters of RoF system are given in table 1.1. For calculating the optimized values of both the parameters, CNR is taken as a prime parameter. CNR of a Radio over fibre link is given by the following expression

$$\text{CNR obtained} = \frac{Power\ contained\ in\ t\square e\ carrier\ signal}{Power\ coressponding\ to\ the\ noise\ signal}$$

$$= \frac{2r^2x^4J^2}{\frac{LW_{RF}}{\pi}\tan\left[\frac{\pi}{2}e^{2TW_t\tau DD_1 p}\right]F_0} \quad (3)$$

Where R is the responsivity taken to be 1A/W, x corresponds to a constant depending upon additional losses of fibre and MZM losses. J is the ration of first-order Bessel function and second-order Bessel function. LW_{RF} denotes the full linewidth of RF oscillator at half maximum; TW_t corresponds to total linewidth of the laser diode and RF oscillator. DD denotes the differential delay. The work is further enhanced by finding the reference CNR which gives an approximate value of Carrier to Noise ratio and it has found to be around 28 dB approx. Now the range of linewidth of RF oscillator is considered between 0.1 and 10 Hz including the extremes and for laser diode it is taken to be 100 to 624MHz [7]. For calculating the CNR_0, we set p_0 to 0.5 denoting half-power bandwidth filter, γ_{RF0} to π, depicting linewidth of RF oscillator be 1 Hz, and zero laser linewidth. Parameters to be used in design while using particle swarm optimization technique

- Linewidth of Laser
- Linewidth of oscillator
- Length of the fibre

IV.II The objective function

The function mentioned below gives a mathematical equation to minimize the losses due to phase noise processes by adjusting the linewidth of the laser diode and RF Oscillator.

$$F_{min=}\text{Sqrt}(\text{CNR-CNR}_o)^2 \quad (4)$$

The minimization process is subjected to

$$100\text{Mhz} \le £_{LD} \le 624\text{Mhz} \quad (5)$$
$$0.1 \le £_{RF} \le 10\text{Hz} \quad (6)$$

The PSO techniques provide a simplified and basic algorithm. The particles are randomly distributed in space and each of the particles has its own velocity and position. With each iteration the particle possesses the best position in reference to oneself, this is denoted by its pbest and the best position among the whole of the group or swarm is referred to as the gbest [3]. The modified velocity of each particle can be computed as given in equation (7). Similarly, the particle position can be updated as given in equation (8)

$$v_k^{i+1} = w^i.v_k^i + q_1.R_1.\left(pbest_k - x_k^i\right) + q_2.R_2.(gbest_k - x_k^i) \quad (7)$$

$$x_k^{i+1} = x_k^i + v_k^{i+1} \quad (8)$$

Where R_1 and R_2 are random numbers which can have any value between 0 and 1

v_k^i is the current velocity of a particle k at i^{th} iteration

v_k^{i+1} is the velocity of a particle k at $i+1^{th}$ iteration
$v_k^{min} \le v_k^i < v_k^{max}$ are the maximum and minimum values of velocity of a the the particle
x_k^i is the current position of the particle k at i^{th} iteration.
x_k^{i+1} is the position of a particle k at $i+1^{th}$ iteration
$pbest_k$ is the personal best of particle k
$gbest_k$ is the global best of particle k
q_1 is the acceleration constant number 1 showing social quality
q_2 is the acceleration constant number 2 showing cognitive quality
w^i is the inertia weight factor which provides dynamic updating to each particle

Now with an objective to minimize this error function and applying the algorithm as explained above, dynamic results are obtained. Following steps has been used to bring about the optimization process and achieve the desired results.

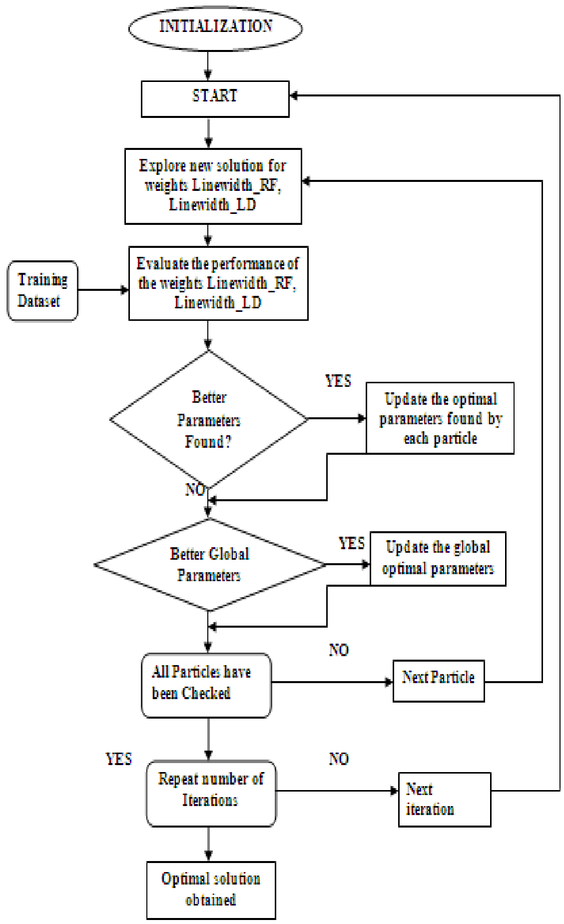
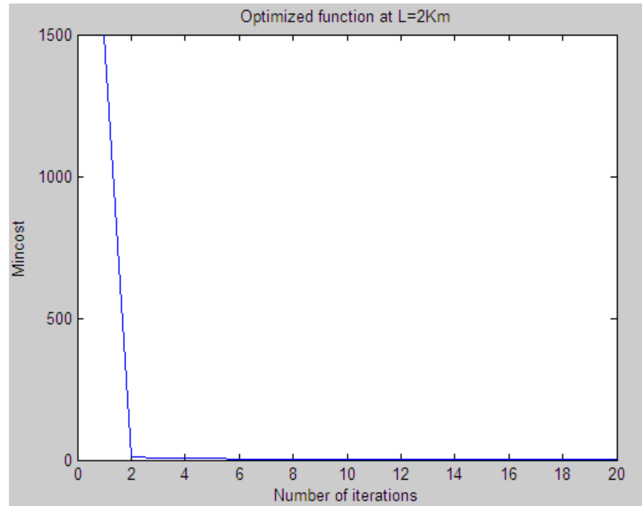


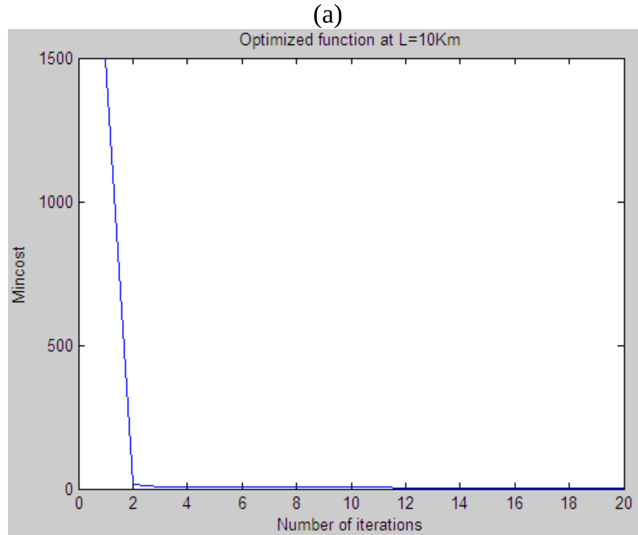
Fig.2. Flowchart of implementation of Particle Swarm Optimization.

V. RESULTS AND DISCUSSION

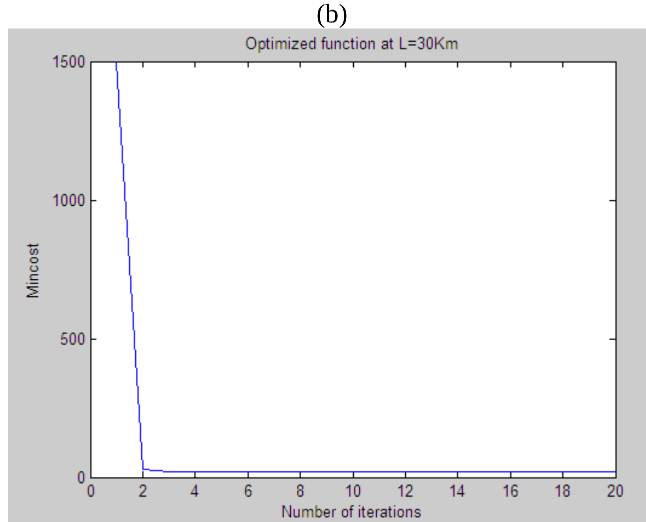
The work undertaken is implemented using particle swarm optimization algorithm in conjunction with the Radio over Fiber mathematical system in MATLAB 9.0. The work involves the optimized values of RF linewidth and LD linewidth using PSO, such that when these values are embedded in the RoF system, it gives the least deviation from the desired CNR value. Then the objective function as mentioned in the present work is minimized by applying PSO and finding the corresponding pbest and gbest through velocity and position updation. The Min cost function indicates the error function to be optimized. The optimization process takes place at a fibre length of 2 Km, 10 Km and 30 Km as shown in Fig.3. It indicates the optimization of fitness function at the vertical axis and number of iterations at the horizontal axis. The fitness function is the squared error function which involves an actual Carrier to Noise ratio and reference Carrier to Noise ratio. By using the standard values [6], CNR (reference) is obtained to be around 28dB.



(a)



(b)



(c)

Fig.3.Optimized function at (a) L=2Km, (b) 10Km and (c) 30 Km

At L=2 km, the function gets perfect zero error at 2nd iteration. As the length of fibre is only a few km so the possibility of attenuation also reduces as it gets less time for propagation leading to not much greater distortions. When an optical fibre of length 10 Km is deployed, it is optimized after 3rd iteration but before the 4th one. As we keep on increasing the length of fibre so does the error keeps on increasing due to addition of path noises which can be counterfeit by choosing appropriate linewidth which reduces phase noises and leads to an acceptable level of Carrier to Noise Ratio. With the further increase in the length of fibre to 30 km, the function gets optimized after the 10th iteration and takes a considerable time to obtain the final position. Thus with the increase in the length of the fibre, the optimized function takes much more time and even the number of iterations to achieve the minimized function. CNR penalty is the ratio of reference CNR to real-time or obtained CNR.

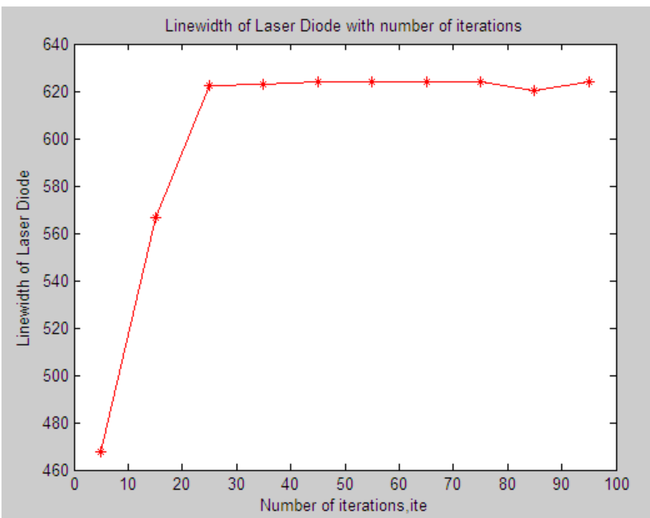


Fig.4. variation of the linewidth of laser diode w.r.t number of iterations

The Linewidth of the laser diode was provided with a range of 100Hz to 624Hz, in accordance with the practical ranges available. Around 5th iteration, linewidth of laser diode was around 465 Hz, however with the increase in number of iterations it follows an increment fashion, and obtains around 624 Hz after 20th iterations and further follows a stable trend with few dips at 80th iteration, Thus it can be observed, higher the value of linewidth of laser greater will be the Carrier to noise ratio. Further, the number of iterations has been fixed to 20 iterations as is it gives an optimized result at any length of fibre or at least up to 30 Km. As we move on to the higher values from 0.1 to 1 Hz and then to 10 Hz, a 20 dB penalty is introduced. So lower the value of linewidth lesser is the CNR penalty. Even a small change in the linewidth of RF oscillator from 0.1 to 10Hz gives a large penalty of 20 dB which is unacceptable in the communication field.

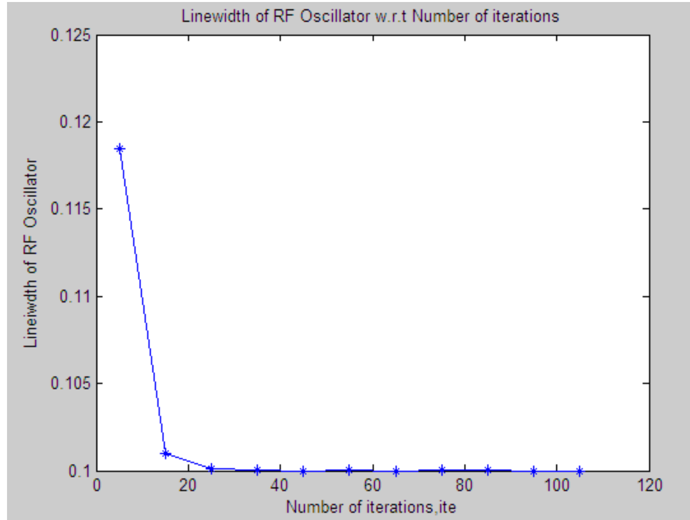


Fig.5.Variation of the linewidth of RF oscillator w.r.t number of iterations

Further, the number of iterations has been fixed to 20 iterations as is it gives an optimized result at any length of fibre or at least up to 30 Km. In fig 1.3 CNR penalty is calculated at RF Linewidth of 0.1 Hz, 1 Hz and 10 Hz with the percentage of received power denoted by p at x-axis. As we move on to the higher values from 0.1 to 1 Hz and then to 10 Hz, a 20 dB penalty is introduced. So least the value of linewidth lesser is the CNR penalty. Even a small change in the RF oscillator linewidth from 0.1 to 10Hz gives a large penalty of 20 dB which is unacceptable in the communication field.

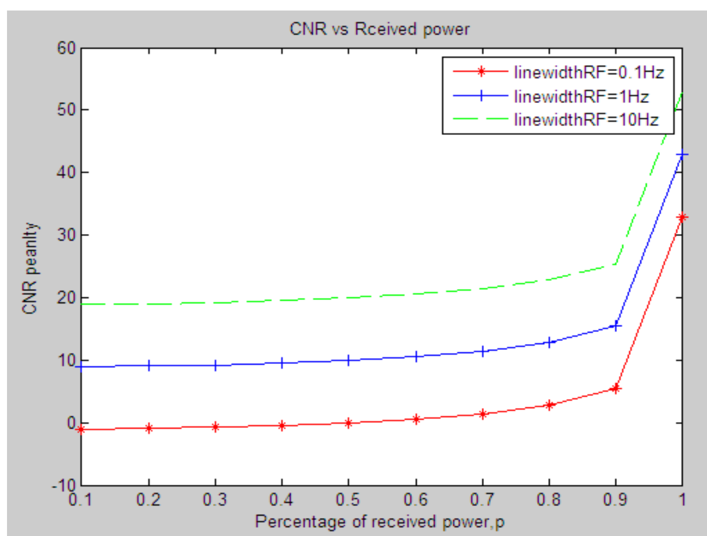


Fig.6. Variation of CNR penalty with changing the value of RF oscillator linewidth

Table 2 Value of linewidth of RF Oscillator and Laser Diode at L= 2,10 and 30 in Km

Length of Fiber, L(Km)	The linewidth of RF Oscillator(Hz)	The linewidth of LD (MHz)
2	0.1001107	571.2951
10	0.1002415	421.1735
30	0.1002619	410.7692

The next result shows the variation in CNR penalty with the changing value of linewidth of LD when we transmit the optical signal through different lengths of fibre as in Fig.5. As we keep on increasing the transmission length the CNR penalty increases. Thus when a shorter distance of 2 km is to be traversed, the CNR penalty remains 0 dB for a significant value of LD lineiwdth. However, as the length of the fibre keeps on increasing so does the CNR penalty. From 2 km to 30 km, a 5 dB penalty has been introduced.

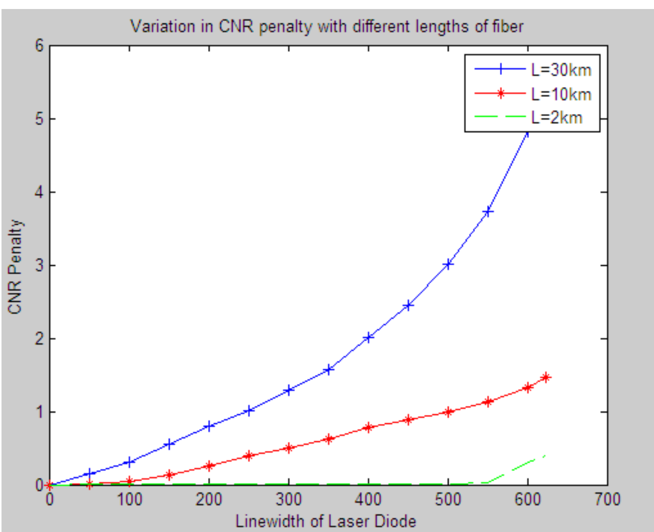


Fig.7. CNR penalty at varied lengths of fibre

The reason can be attributed to the channel noise, dispersions and other environmental factors which lead to the degradation of the signal. However, still, this value of deterioration is far below the conventional communication channels. It can be seen that even a minor shift in RF oscillator linewidth gives rise to 20 dB penalty, whereas when the LD linewidth is changed from 100MHz to 624 MHz, a minor penalty of 5 dB takes place. Thus RF Oscillator linewidth plays a more dominant role with reference to Carrier to Noise ratio of the RoF system. Further, table 1.3 gives the value of time elapsed or time taken by the program to execute the PSO program on different lengths of fibre. It is evident that as the number of iterations increase, the time elapsed eventually increases. Here too as mentioned for the above graphs, the number of iterations has been fixed to 20 iterations. The time elapsed for 2 Km, 10 Km and 30 Km is 0.674493 sec, 0.678670 sec and 0.684068 sec respectively.

Table 3 Time elapsed at L= 2, 10, 30 and 50 Km

Length of fiber(Km)	Time elapsed(sec)
2	0.674493
10	0.678670
30	0.684068
50	0.731197

As explained earlier in table 2 which gives different values of the linewidth of RF Oscillator and LD at the same iteration number when repeatedly used and worked with. Hence, a standard deviation is found in each iteration to show the variation under each iteration. The standard deviation is denoted by SD and the calculated value is given at the end of each row. It gives us information about how much the value of linewidth of either RF Oscillator or Laser Diode varies from one time to another. And it is worth noticing that RF oscillator deviates less as compared to Laser diodes linewidth, this can be attributed to the fact that RF oscillator has more effect on the CNR variation than the laser diode as shown in the above figures. Here also the number of iterations is fixed to 20 as suitable for the work. The standard deviation is calculated at different lengths of fibre denoted by L.

Table 4 Value of Standard deviation of linewidths at L= 2, 10 and 30 km.

Length of the fibre in Km (L)	Standard Deviation (RF)	Standard Deviation(LD)
2	**0.000040**	**1.83647**
10	**0.000051**	**3.11869**
30	**0.000032**	**1.66857**

VI. CONCLUSION AND FUTURE SCOPE

In this paper, we have discussed the variation in Carrier to noise ratio when varied lengths of fibre were used. Here CNR is limited by phase noises of RF Oscillator and a laser diode. Nature-based algorithm PSO was used to find the optimal value of both the linewidths in reference to a pre derived value of carrier to noise ratio mentioned as reference CNR. It was seen that the variation in the linewidth of the laser diode at any length produces a meagre change, however, a small change in RF oscillator linewidth leads to significant degradation. It was also observed that as the length of the fibre keeps on increasing, CNR penalty also increases and the corresponding linewidth of RF oscillator and linewidth varies as mentioned.

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