An Optimization Algorithm for Optical Gain in the Multi-EDFAs-based Fiber-optic Time Synchronization

Bo Liu
National Time Service Center
Chinese Academy of Sciences
Xi'an, China

State Key Laboratory of Transient Optics and Photonics
Chinese Academy of Sciences
Xi'an, China
313784890@qq.com

Weicheng Kong, Xinxing Guo, Bo Li,Shougang Zhang, Ruifang Dong, Tao Liu
University of Chinese Academy of Sciences
Chinese Academy of Sciences
Beijing, China

Key Laboratory of Time and Frequency Primary Standards
Chinese Academy of Sciences
Xi'an, China

***Summary*—This article reports an optimization model of optical fiber time synchronization EDFA gain coefficient based on genetic algorithm (G A). According to a series of parameters such as the distance and attenuation of each section of optical fiber, the EDFA gain coefficient of each node is obtained for the purpose of maximizing the signal-to-noise ratio, SNR. This algorithm is further exploited for regulating the gains of bidirectional amplifiers, allowing optimization of the performance of the link. The developed algorithm was tested experimentally done with 210- and 300-km-long links in the laboratory, incorporating three and four amplifiers. The results suggest that, comparing with the fixed gain coefficient setting, the proposed solutions allow optimizing the SNR by 3-5 dB and reduce the phase jitter by about 20%.**

Keywords—time synchronization; signal-to-noise ratio; genetic algorithm.

I. INTRODUCTION

High-precision time signal transmission technology plays a vital role in deep space exploration, satellite navigation, power transmission, scientific research and other fields [1-2]. The use of optical fiber links for high-precision long-distance time signal transmission has attracted wide attention [3]. In order to compensate the transmission loss of the fiber, the long-distance optical fiber communication must carry out the relay amplification of the optical signal [4]. The advent of EDFA with good forward and backward transmission delay symmetry and high isolation is a revolutionary breakthrough in the field of optical fiber time synchronization. However, there are some negative features of EDFAs, resulting from the possibility of free propagation of backscattered signals and amplified spontaneous emission (ASE) [5,6]. These signals, originating from the single Rayleigh backscattering (SRB) and the double Rayleigh backscattering (DRB) occurring in the fiber spans connecting the amplifiers, reach the local and far ends of the link together with the main signals. So, the problem becomes essential about the influence of these unwanted signals on the stability of the transfer, i.e., about the reduction of SNR [7]. In order to obtain the best optical fiber time-frequency transmission performance, the gain and number of bidirectional amplifiers on the link need to be optimized to obtain the best received SNR [8,9]. For solving the above-mentioned problems, the EDFA gain coefficient optimization model for fiber-based time signal transmission is established according to the type of link noise, and the objective function to optimize the SNR is further obtained. In order to speed up the convergence speed of the algorithm and improve the global convergence of the algorithm, this paper proposes a EDFA gain coefficient optimization based on GA.

II. METHODS/RESULTS

Figure 1 shows a two-way fiber time transfer model with EDFAs.

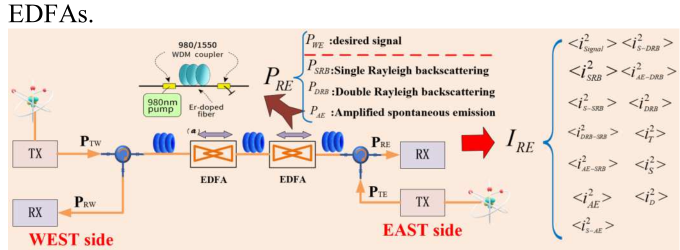

Fig.1 Schematic setup of the time transfer link and bidirectional amplifiers.

We can write the received power on the eastern side of the link as

$$P_{RE} = P_{EW} + \left(P_{SRB} + P_{DRB} + P_{AE}\right) \tag{1}$$

The detector at the receiving side converts the received optical signal into electrical signal according to the square law detection. The received signal contains not only the required signal current, but also the noise component apart. The electrical noise variance is shown in Fig.1(I_{RE}).

Based on the above analysis, the SNR_E can be calculated as:

$$SNR_E = \frac{(\Re \cdot P_{EW})^2}{\sum 0.5\sigma_{(i)}^2} \tag{2}$$

Where $\Re$ is the responsivity of the photo detector (PD). For each fixed length optical fiber link, some gains can be found to obtain the maximum SNR. This can be explained that for some low gain, the signal reaching the east end of the link is very weak, while the noise generated by the backscattering of light from the east side laser in the east side fiber is relatively high, resulting in a low overall SNR. When the gain of the amplifier is too high, the signal reaching the east side of the link is also very high; In this case, the backscattering of light from the far side is mainly caused by the light from the east side.

The purpose of this paper is to select the best gain of EDFA at each relay point according to the power of the transmitter, the length of each optical fiber distance in the link and the attenuation factor to maximize the $\mathrm{SNR_E}$ at the receiver and reduce the phase jitter in the transmission link. Therefore, the objective function of the system is

$$MAX\ \mathrm{mi}\,ze\quad SNR_E$$
$$s.t.\begin{cases}0.2 \le \alpha_i \le 0.3, i = 1,2,3\ldots N\\ 50 \le l_i \le 100, i = 1,2,3\ldots N\\ 0 \le G_i \le 25, i = 1,2,3\ldots N\end{cases} \tag{3}$$

The objective function has three constraint functions. The first constraint is that the attenuation coefficient α_i is between 0.2dB~0.3dB. The second is that the length l_i of the fiber is 50 ~ 100km. It may be taken as an experience that the gain of the EDFA should not exceed about 25dB to have some safety margin against excessive noise caused by amplification of backscattered signals. Hence, the third is that the gain coefficient G_i of each EDFA is between 0 ~ 25dB.

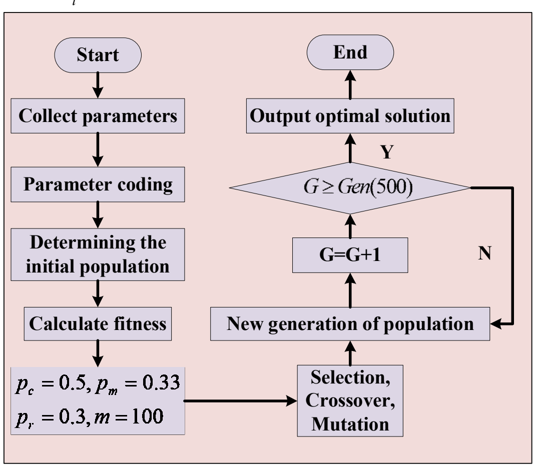

Fig.2 Flow chart of genetic algorithm.

Therefore, this paper selects the GA as the optimal solution to obtain the objective function $MAX\ \mathrm{mi}\,ze\quad SNR_E$. GA is based on the law of survival of the natural fittest, and the genes of the excellent individuals in the population are inherited. The better the individual with greater fitness is, the better the population is optimized, and the obtained solution is closer to the optimal solution. The population is repeatedly iteratively optimized to obtain the optimal solution of the target problem. As show in Fig.2, firstly, the population size *m*, crossover probability p_c, mutation probability p_m and termination condition of operation parameters in GA are determined according to the attenuation factor, length and dispersion coefficient of each fiber. After a series of steps of encoding, determining the initial population, selection, crossover, mutation and fitness evaluation, the optimal solution of the objective function is obtained, and the gain coefficient of each EDFA is finally obtained.

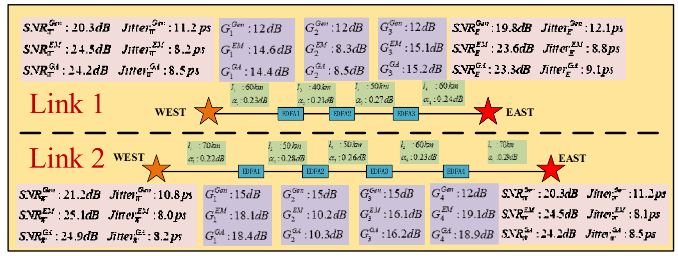

Fig.3 Schematic diagram of SNR and phase jitter of three algorithms in 210km and 300km optical fiber links.

In the optimization model of EDFA gain coefficient of long-distance optical fiber link based on GA, the simulation and solution of the algorithm are realized by MATLAB. The general EDFA gain factor setting algorithm（Gen）, GA and enumeration method (EM) are compared and verified in 210km (3 EDFAs) and 300km (4 EDFAs) spooled fibers in the laboratory, as shown in Figure 3. In 210km link, the optical fiber distance is 60km, 40km, 50km, 60km respectively. The gain factor for Gen is 12dB. Global optimal solution obtained by EM: $G_1^{EM}:14.6dB$, $G_2^{EM}:8.3dB$, $G_3^{EM}:15.1dB$. Obtaining by GA: $G_1^{GA}:14.4dB$, $G_2^{GA}:8.5dB$, $G_3^{GA}:15.2dB$. Comparing the three algorithms, the SNR and jitter of conventional settings are not ideal from east side to west side, SNR_W^{Gen} is only 20.3dB, $Jitter_W^{Gen}$ is 11.2ps. Using GA, the SNR has been greatly improved, SNR_W^{GA} is 24.2dB, increased by 3.9dB, jitter is also reduced by 2.7ps, $Jitter_W^{EM}$ is 8.5ps. The EM has the best effect, SNR_W^{EM} is 24.5dB, and $Jitter_W^{EM}$ is 8.2ps, but due to the time complexity of the objective function, the convergence speed of the EM is much lower than that of the GA. Similar results can be seen for SNR and phase jitters from west side to east side and on 300 km optical fibers.

III. Conclusions

This paper presents a genetic algorithm based optimization of EDFA gain coefficient in long-distance optical fiber link. This is an effective technical method, which can quickly find the best gain of each EDFA in the optical fiber time transmission link, so as to obtain the best SNR and phase jitter at the receiver. This method has achieved good results in the laboratory. In the next step, the algorithm will be verified in the field link.

References

[1] J. Kodet, P. Pánek, and I. Procházka, “Two-way time transfer via optical fiber providing subpicosecond precision and high temperature stability,” Metrologia, vol.53, pp.18-26, Feb 2016.

[2] C. Clivatiet,“A VLBI experiment using a remote atomic clock via acoherent fibre link,” Sci. Rep, vol. 7, pp.40-48, Feb.2017.

[3] M. Amemiya, M. Imae, Y. Fujii, T. Suzuyama, F. Hong, M. Takamoto, Precise frequency comparison system using bidirectional optical amplifiers, IEEE Trans. Instrum. Meas, vol. 59 (3), pp. 631–640, 2010.

[4] C. R. Giles and E. Desurvire,“ Modeling erbium-doped fiber amplifiers,” J.Lightw. Technol, vol. 9, pp.271–283, Feb 1991.

[5] A. Bercy, F. Stefani, O. Lopez, C. Chardonnet, P. Pottie, and A.Amy-Klein,“Two-way optical frequency comparisons at 5×10−21 relative

stability over 100-km telecommunication network fibers," Phys. Rev.A, Gen.Phys, vol. 90, pp.061802, 2014.

[6] W. Wenjun, D. Shaowu, L. Huanxin, Z. Hong,"Two-way satellite time and frequency transfer: overview, recent developments and application," European Frequency and Time Forum (EFTF), pp. 121–125, 2015.

[7] C. de la Morena, et al," Fully digital and White Rabbit-synchronized low-level RF system for LIPAc,"IEEE Trans, vol. 65 (1), pp.514–522, 2018.

[8] Ł. Sliwczynski, P. Krehlik, K. Salwik," Modeling and optimization of bidirectional fiber-optic links for time and frequency transfer,"IEEE Trans, vol.66 (3), pp. 632–642, 2019.

[9] C. Lisdat, G. Grosche, et al,"A clock network for geodesy and fundamental science,"Nat. Commun, vol.7, p. 12443, 2016.