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Minimizing the Detrimental Effect Of Out-Of- Bound Non Linearities in Optical Network Using Adaptive Optical Equalizer

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Abstract
The need for high capacity long haul telecommunication system to carry huge traffic demands in recent times has lead to the use of optic fiber communication system because of its high capacity carrying advantage over wireless systems. But optic fiber signals suffer some signal impairment issues such as nonlinearity which tends to degrade its transmission performance. This paper proposed the use of adaptive optical equalizer to mitigate such impairments. To achieve that, a simulink model of the system was first developed for simulation experiments. Then the impact of out-of-bound nonlinear signal on the three key performance indicators (Q Factor, Bit Error Ratio and Eye Height) studied was evaluated. An adaptive optical equalizer system was them applied to the network and measurements of the effect of the presence of the adaptive equalizer in an out-of - bound nonlinear environment was taken for the three key performance indicators. When the new results were compared with that of the previously evaluated data (without the adaptive equalizer), it was observed that the presence of adaptive equalizer brought a great improvement on the system, which was attributed to the mitigating effect of the equalizer. Thus it was concluded that in an out-of -bound nonlinear environment, adaptive equalization can be used to mitigate the effect of nonlinear signal thereof..
Keywords: *Nonlinear optic fiber, self-phase modulation, Kerr effect, refractive index, nonlinearity mitigation.*

I. Introduction

Non linearity in optical systems represents a fundamental limiting mechanism to the efficient operations of optical networks [1]. It's a major drawback in optical communication system. Several nonlinear effects occur along the optic fiber transmission system which causes disproportionate attenuation, usually at high optical power levels [2]. This nonlinear factor causes the optical power from one mode to be transferred in either the forward or backward direction to the same, or other nodes, at a different frequency [2].

Some of the manifestations of this problem include inability to download important files, slow down in web surfing or stopping completely. It also impedes ability to download music or play games [3]. For voice issues, users will experience frequent call drops, inability to initiate calls, digital garbling and noise during calls. These problems create a lot of customer disaffection for users of optical networks. To business users the issue of slow network speed can be very frustrating.

System designers must be aware of these limitations and the steps that can be taken to minimize the detrimental effects of fiber nonlinearities.

Given the huge amount of traffic on the optical networks, data loss or data instability would be disastrous. Therefore the survivability of optical networks is a very important issue.

II. Thoery of Work

In an optic fiber communication system, light is confined to a small transverse region, so that even moderate optical powers lead to high optical intensities. Also in optic fiber, light often propagates over considerable distances causing in effect non-linearity issues of substantial effects [4]. Non-linearity effect is proportional to the optical power density of signal and it significantly affects signal phase, pulse shape and optical evaluations [4]. In a non-linear relationship, changes in the output do not change in direct proportion to changes in any of the inputs.

Non-linearity also occurs in optic fiber due to intensity dependence of refractive index of the medium or due to inelastic-scattering phenomenon induced directly by insertion of the optic fiber into an intense external electric field.

Various types of nonlinear effects include self-phase modulation, cross-phase modulation and four-wave mixing.

The nonlinear effects are separated on the basis of their characteristics. There are two such categories; one is scattering effect and the other is Kerr effect. Scattering effect is the loss of optical signal caused by the diffusion of a light beam, where the diffusion itself is caused by microscopic variations in the fiber. Here scattering occurs when a light signal impinges an impurity in the fiber structure [5].

Kerr effect is as a result of the fact that phase delay in the fiber gets larger as optical intensity increases. Kerr effect induces a power dependent nonlinear distortion for the optical signal propagating in the optic fiber. Kerr effect responds very quickly to changes in electric field, hence optical light inside a fiber cable can be modulated with devices at frequencies as high as 10GHZ creating nonlinearity in the system [6].

Non-linearity is of particular concern for the designers and users of fiber-based communication systems since long haul transmission systems rely on highly coherent laser energy to generate and transmit signals over long lengths of fiber.

In general, all nonlinear effects are weak and depend on long interaction length to build up. So any mechanism that reduces interaction length decreases the effect of non-linearity. One of such mechanisms is adaptive equalization.

A wide variety of adaptive equalization methods have been used to treat nonlinearity, in different transmission scenarios.

Significant gain can be achieved by using any of the equalization methods. Still, there is much work to be done on this subject, such as designing new and efficient algorithms tailored for nonlinearity mitigation, as well as real-time implementation of the current algorithms.

Many other techniques have been developed to compensate for the non linearity effect in optical networks. One of the techniques studied is the fiber itself whose characteristics can be tuned according to the requirements [7]. Oldest one being Dispersion-Shifted Fibers (DSF) which was used to compensate dispersion at 1.55 mm wavelength i.e. zero dispersion wavelength [8]. But at this wavelength other effects such as Four Wave Mixing (FWM) and Cross Phase Mixing (XPM) were very high, therefore, Dispersion Compensating Fiber (DCF) was used having dispersion negative value equal to the transmitting fiber [8]. DCF can be used as pre-compensation, post compensation or in-line compensation fiber; but pre-compensation was preferred as it is robust to non linear phase noise [9]. Another such technique was Dispersion Managed (DM) cables or Reverse–Dispersion Fiber (RDF) based on mixing in each individual span a positive–dispersion fiber and a negative dispersion fiber that cancels overall dispersion and had the advantage of reducing the effects like FWM and XPM [8]. Also, this technique was lately used for dispersion compensation in Wave Division Multiplexing (WDM) systems which used Single Mode Fiber having large effective area and Bit Error Rate (BER) ≤ 10-9 was achieved [10]..

Most commonly used technique in dealing with non linearity issues was the use of equalization circuits. Hu[11] had proposed a design of integrated distributed transversal equalizers with focus on delay lines and gain stages which reduces non-linearity produced due to kerr effect. Crivelli [12] had investigated the combined adaptive digital equalization of all-order PMD, CD, and laser phase noise in high speed coherent optical transmission systems. Results showed that the new four dimensional equalizer can compensate the non-linearity issues up to 1000 km of standard single-mode fiber [12]. Another EDC technique was using an Asymmetric Mac-Zehnder Interferometer (AMZI) with a large Differential Time Delay (DTD). This process suppressed fiber nonlinearity and thermal noise [13]. MZI was also used as dispersion slope equalizer for the Spectra Amplitude Coding-Optical Code Division Multiple Access (SAC-OCDMA) system integrated with Arrayed-Waveguide Grating (AWG) router coder to improve the distortion in the system [14].

Dual-electrode Mach-Zehnder modulator and an Erbium-Doped Fiber Amplifier (EDFA) were also used to optimize the performances of radio on fiber (RoF) systems by enhancing SNDR of the system.

A. Gorshtein designed adaptive Least Mean Square (LMS) based equalizer that compensated CD and PMD. Output of the equalizer contained Intersymbol Interference (ISI) introduced by the Anti-Aliasing Filter (AAF) which was compensated using independent (non-linear) equalizer Maximum Likelihood Sequence Estimation (MLSE) [15]. Poe [16] presented a Feed Forward Equalizer (FFE) with adjustable tap coefficients to reduce the effect of Inter-Symbol Interference (ISI) caused due to dispersion in optical fiber.

The survivability and usability of optical networks can be achieved through any or combination of these various restoration mechanisms. Restoration mechanisms try to allocate the necessary network resources after a failure occurs. For protection, the interruption of the connection service can be very short, for example, if the data is sent simultaneously on the backup path or detour paths, almost no service interruption at all can be achieved assuming a single failure model. However this performance is obtained at the price of allocating the backup resource for the connection even when there is no failure. In comparison, restoration schemes do not allocate resources for recovery until the failure occurs. In that case, a backup path or detour path is routed on runtime. Hence there is a short time service interruption before the connection works again and there might be some data loss due to the service interruption. As mentioned above, a traditional WDM-PON is currently faced with the challenge to increase its networking capability and bandwidth capacity.

Basically the source of nonlinearity can be divided into two groups: in-band nonlinearity which involves interactions of frequency components that are within the receiver's bandwidth and out-of –band nonlinearity which is produced by interactions with channels that are outside the received bandwidth. Their treatment is very different.
In-band nonlinearity signals are deterministic signal-dependent effect and can be reduced by means of digital back propagation or sequence detection, while out-of band nonlinearity can be treated using adaptive equalizer techniques.
This work dealt with out-of band nonlinearity in optic fiber using adaptive equalization algorithm with optiwave software.

III. Methodogy

3.1 Computer modeling for simulations:
Optiwave system is a modern optical communication system that can be used to conduct studies on optical systems [17]. In this paper Optiwave system and its software described in Fig. 1 together with fiber bragg grating using the simulation parameters in Table1were used to conduct the simulation works.

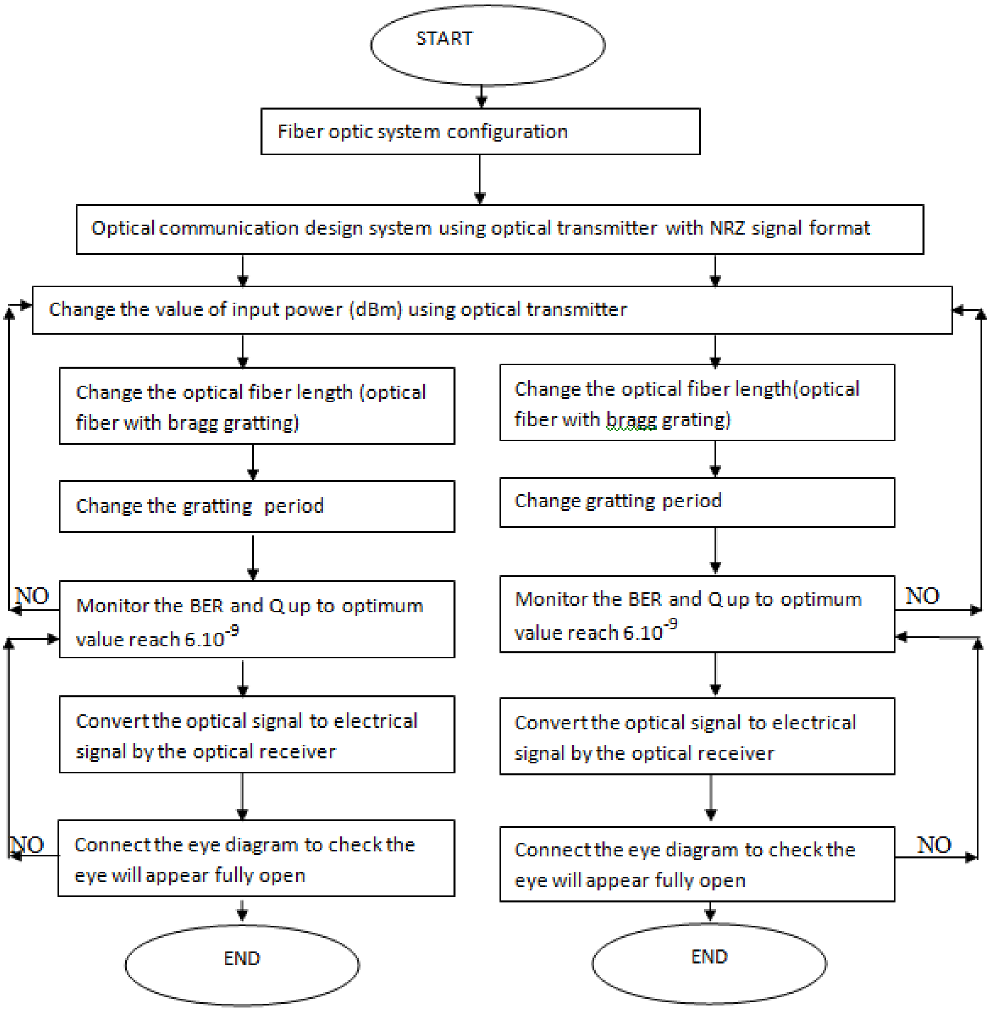

Fig. 1: The computer model of Optiwave system

Use of fiber bragg grating (FBG)
FBG is used for fixing the wavelengths of fiber lasers, for filtering out certain wavelength components, for gain flattening of fiber amplifiers and for fiber optic sensors.
A FBG is formed by producing a periodic modulation in the refractive index of the core of an optical fiber along the direction of propagation. The periodic pattern creates a bragg grating that acts as a filter, which because of interference, reflects some of the incident optical field.
FBG as shown in Fig. 2 is used in conjunction with the OPTIWAVE model in this paper

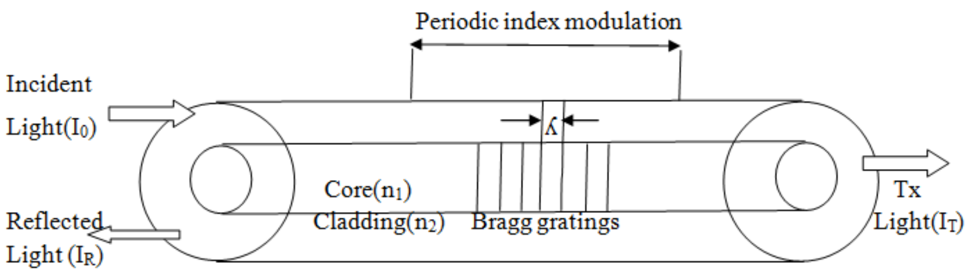

Fig. 2: Fiber Bragg Grating

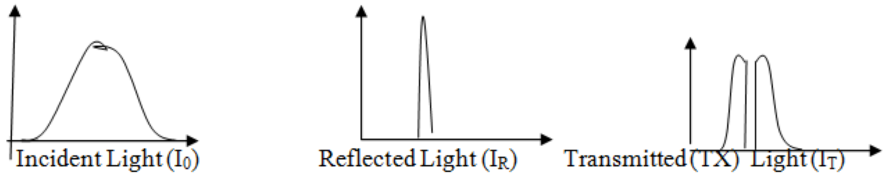

Fig.3: Input, reflected and transmitted samples of Fiber Bragg Grating

Table 1: Simulation parameters

Parameters	Value
Power (dBm)	0-15
Fiber length (Km)	10 – 50
Attenuation (dB/Km)	0.2
Central frequency (THz)	193.1
Wave length (mm)	1550
Dispersion (ps/nm^2/Km)	16.75
Dispersion slop (ps/nm^2/Km)	0.75
Bragg grating length (mm)	0 - 10

3.2: Development of simulink model for experimentations

The simulink platform of the system Fig. 4, used for experimentations in this research was developed

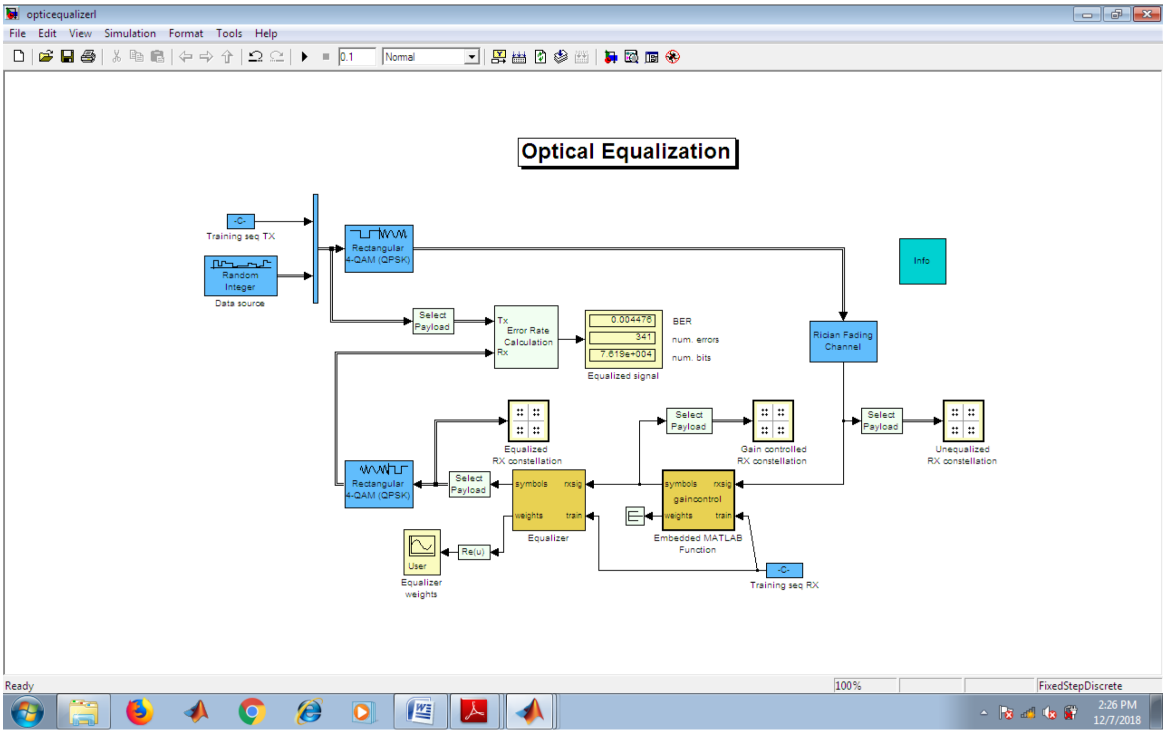

Fig. 4: MATLAB Simulink model for used for experiments (simulations)

This MATHLAB model illustrates how to use blocks that contain embedded MATLAB code describing a communications algorithm. The model uses the embedded MATLAB function block in Simulink to construct adaptive equalizers.

The communications link in this model includes these components:

- A source of random data.
- A source of a constant training sequence.
- A modulator that modulates the data and the training sequence. Each frame comprises 200 data symbols and 50 training symbols.
- A subsystem that models a multipath Rician channel with additive white Gaussian noise.
- An Embedded MATLAB Function block labeled gain control that implements gain control for the received signal using a one-tap equalizer.

In this work, the input power value was adjusted until the optimal values of BER (10^{-9}) is reached, and modified Q = 6 was found and then results taken. The first channel used is a single-mode fiber with bragg grating and the second channel used is CWDM fiber with bragg grating, simulation parameters are shown in the table (1)

IV. Simulations

Evaluation of the quality parameters (The key performance indicators).

The quality parameters evaluated in this work includes the followings

1. Quality Factor Q
2. BER (bit error ratio)
3. Eye diagram

In optical communication systems, only optical signal to noise ratio (OSNR) could not accurately measure the system performance. Typically, a quality factor Q, is a one of the important indicators to measure the optical performance by which to characterize the BER. Q Factor represents SNR (signal to noise ratio) optical for binary/digital optical higher the bit rate, the higher the OSNR (optical signal to noise ratio) required. Q Factor is a key parameter that determines the. performance of a communication channel.

The bit error rate (BER) is the most significant performance parameter of any digital communications system. It is a measure of the probability that any given bit will have been received in error. Also BER as a function of distance in optic fiber is an effective way to show the degradation of the transmission quality as the distance travelled by the signal increases. BER accumulations have been done for each distance ranging and attenuator has been set at 0 dB during measurements. In quality factor, the BER is always the final measure of transmission quality.

The eye diagram is a common indicator of performance in digital transmission systems. The eye diagram is an oscilloscope display of a digital signal, repetitively sampled to get a good representation of its behavior. The eye diagram can also be used to examine signal integrity in a purely digital system, such as fiber optic transmission, network cables or on a circuit board. In a digital optical telecommunications receiver, the incident signals are sampled in the centre of the bit period and the sampled level is compared to a threshold to determine the presence of a one or zero. With threshold detection of this nature errors arise when noise in the system pulls a one signal level below threshold at the sampling point and pushes a zero above threshold.

In this research work the experiments were conducted by taking different lengths of optical fiber and their respective Q factor, bit error rate (BER) and eye height of the received signal and measurements taken before and after applying the equalization algorithm.

4.1: EVALUATION OF THE IMPACT OF NONLINEARITY EFFECTS ON THE THREE KEY PERFORMANCE INDICATORS.

The experimentations on optic fiber system with nonlinearity effects were conducted for Q factor, BER and eye height parameters for various fiber lengths from 50KM up to 300KM and measurements taken as indicated in Tables 2, 3 and 4. The analysis for each parameter were conducted using Figs 5, 6, and7.

Table 2: Impact of nonlinearity effect on Q Factor (before Equalization)

Length of Fiber (KM)	**Q factor**
50	9.13
100	7.12
150	5.35
200	4.78
250	3.17

300	2.83

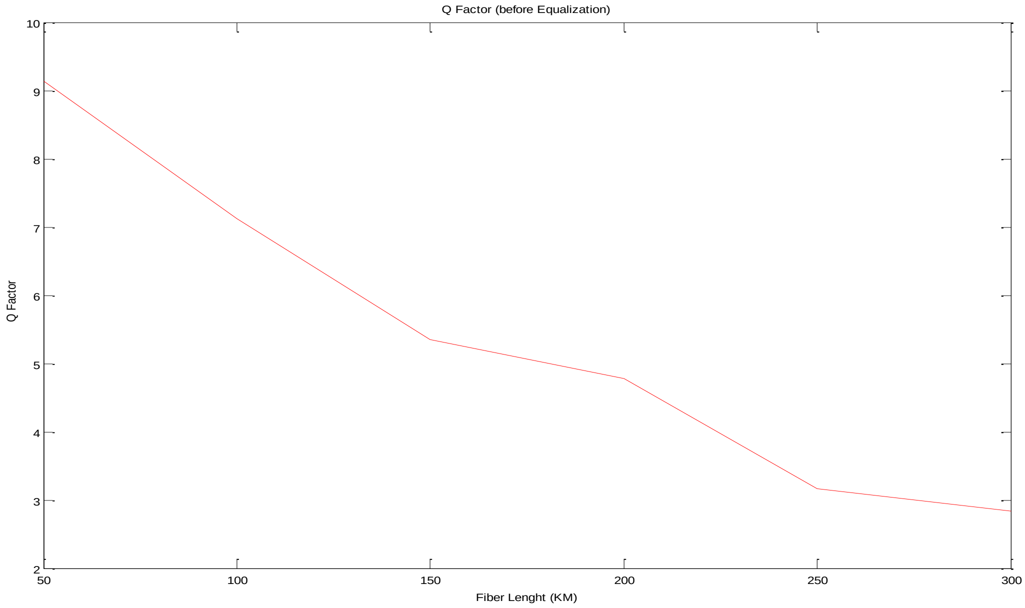

Fig.5: Graph of the Impact of nonlinearity effect on Q Factor Vs length of fiber (before Equalization)

Analysis of the evaluation of the impact of nonlinearity effect on Q factor before equalization

The graph of Q-factor in Fig.5 changes with the open degree of eye diagram as the fiber length changes. More approaches the point of smallest eye diagram opened, the Q-factor is smaller, and the Corresponding BER is bigger. The figure shows clearly that the greater the length of the cable the less the Q Factor.

Table 3: Impact of nonlinearity effect on BER (before Equalization)

Length of Fiber (KM)	**BER (bps)**
50	3.20443e-020
100	5.4293e-013
150	4.3864e-008
200	7.6812e-007
250	7.8812e-007
300	8.0003e-007

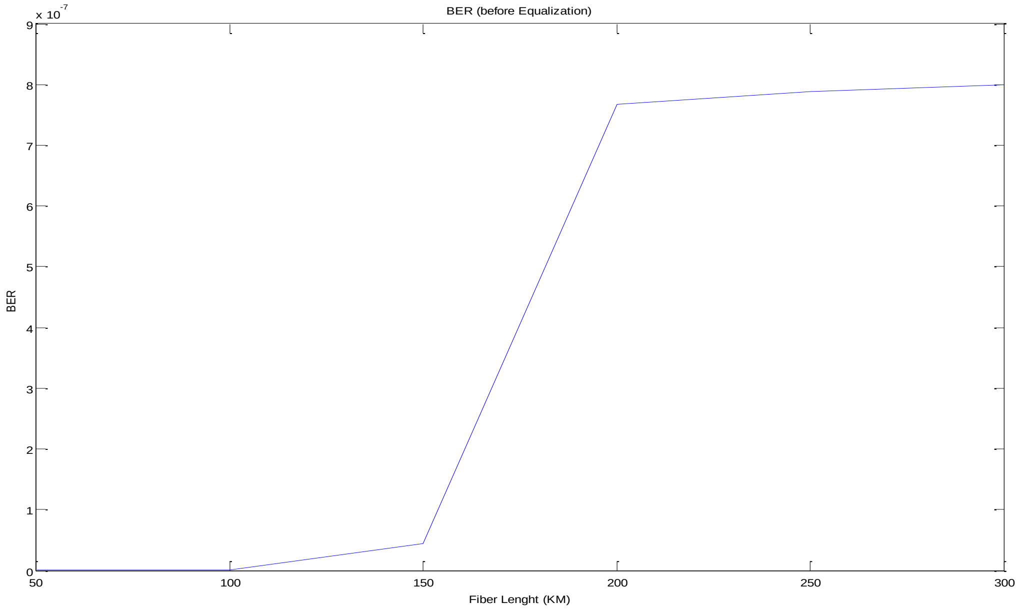

Fig. 6: Graph of BER Vs Length of Fiber before equalization

Analysis of the evaluation of the impact of nonlinearity effect on BER before equalization

Fig. 6 shows an increase in BER as the length of fiber increases. In effect, the greater the BER the more drop calls that are experience in optic fiber network, example GSM networks.

Table 4: Impact of nonlinearity effect on eye height (before Equalization)

Length of Fiber (KM)	eye height
50	0.448
100	0.314
150	0.196
200	0.158
250	0.135
300	0.121

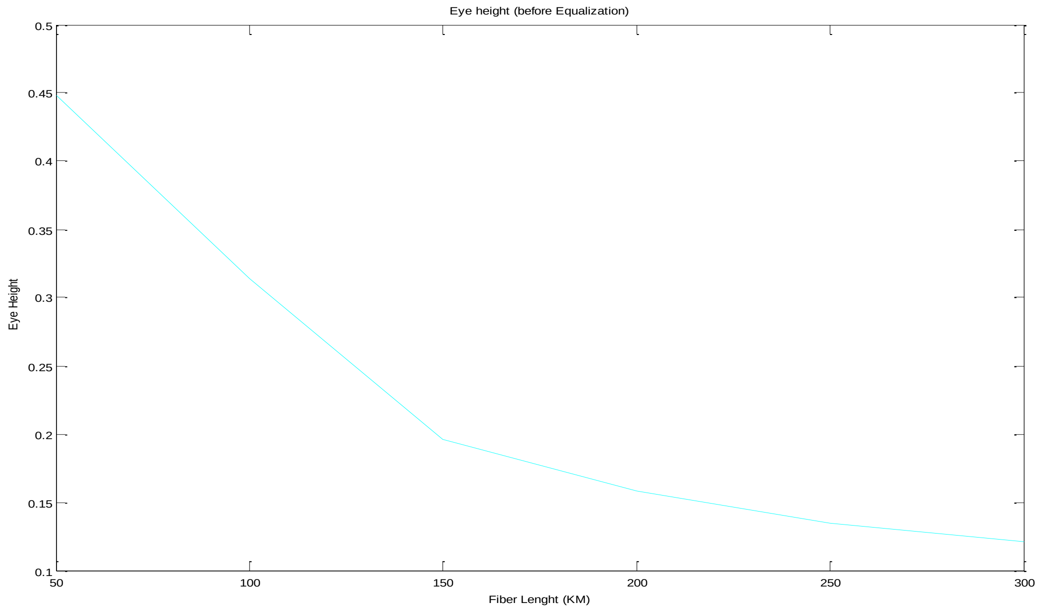

Fig. 7: Graph of Eye Height Vs Length of Fiber before equalization

Analysis of the evaluation of the impact of nonlinearity effect on eye heigth before equalization.
The open degree of eye diagram is affected by the fiber length as shown in Fig. 7. It reduces as the fiber length increases.

4.2: SIMULATIONS ON THE IMPACT OF NONLINEARITY EFFECTS ON THE THREE KEY PERFORMANCE INDICATORS WITH THE APPLICATION OF ADAPTIVE EQUALIZER ALGORITHM.

Afterwards an adaptive equalization algorithm was applied to the system to study the conduct of the three performance indicators in the presence of adaptive equalizer. With the algorithm in the simulink platform, the system was simulated and measurements were taken for the various lengths of the fiber (50KM – 300KM) versus the three parameters of the study (Q factor, BER and eye height). The results of the measurements are shown in tables 5, 6, and 7. And analysis of the results obtained were made using Figs 8, 9, and 10.

Table 5: Impact of nonlinearity effect on Q Factor (after equalization)

Length of Fiber (KM)	**Q factor**
50	18.075
100	15.272
150	10.768
200	9.646
250	7.819
300	6.901

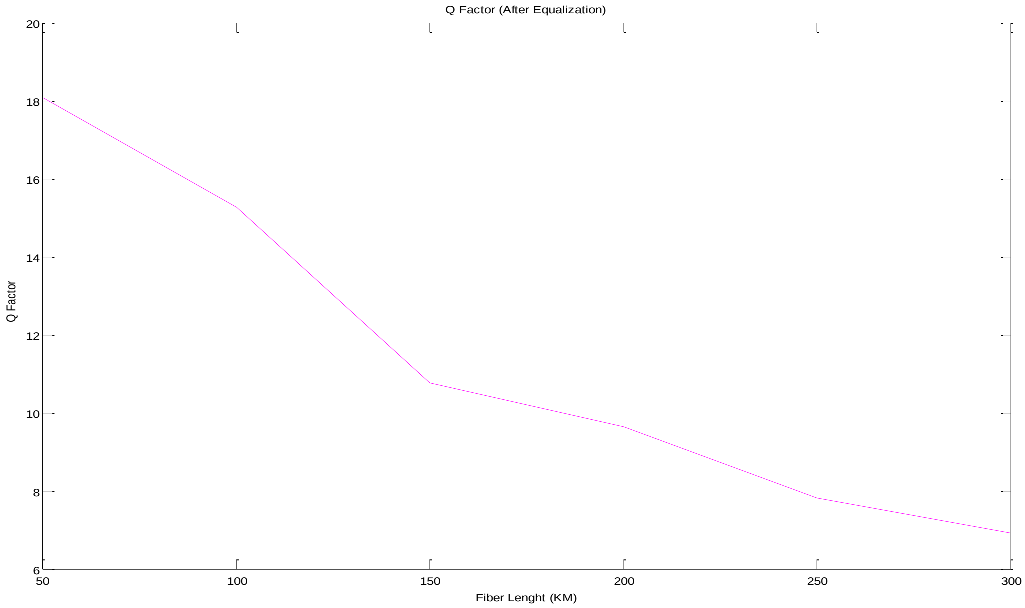

Fig. 8: Graph of Q factor Vs Length of Fiber after equalization

Analysis of the effect of adaptive equalizer on the Q Factor after equalization

As shown in Fig. 8 the Q Factor decreases as the length on th cable increases. The signal quality is high, eye's shape is very good, and the edge neat graph is symmetrical. The curve of Q-factor changes with the open degree of eye diagram as follows: More approaches the point of largest eye diagram opened, the Q-factor is bigger, and the corresponding BER is smaller. It shows that the system have the big capacity under the guarantee of the condition of system bit error rate (BER).

Table 6: Impact of nonlinearity effect on BER (after equalization)

Length of Fiber (KM)	BER (bps)
50	2.4962e-073
100	5.7302e-053
150	2.3370e-027
200	2.44e-022
250	2.47e-022
300	2.49e-022

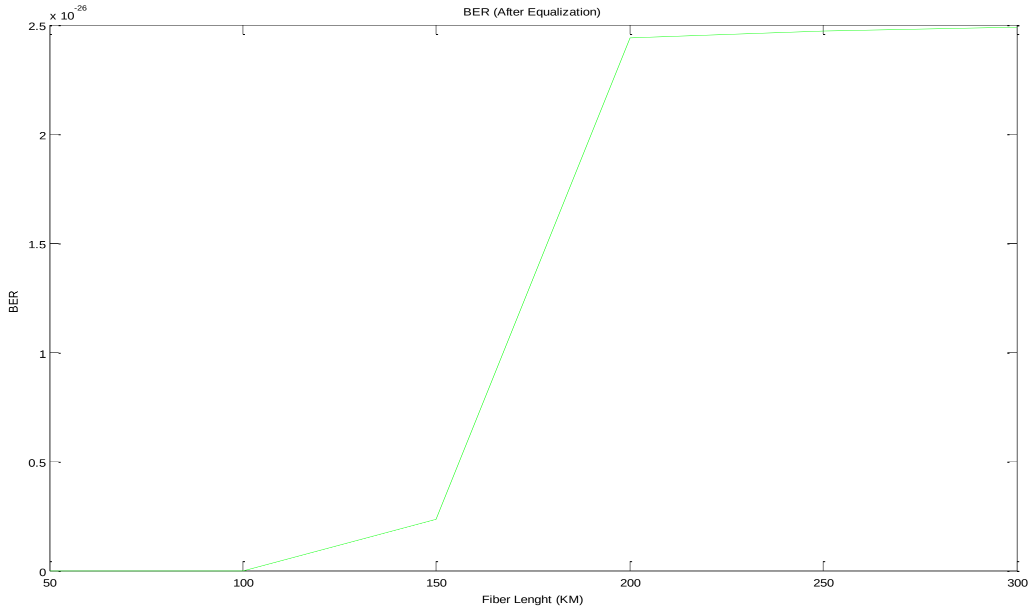

Fig. 9: Graph of BER Vs Length of Fiber after equalization

Analysis of the effect of adaptive equalizer on the BER

Fig. 9 shows a drastic reduction in BER with increase in the cable length and this will improve not only the channel capacity, but the quality of received signal and reduce drop calls.

Table 7: Impact of nonlinearity effect on eye height (after equalization)

Length of Fiber (KM)	eye height
50	0.820
100	0.785
150	0.695
200	0.660
250	0.507
300	0.451

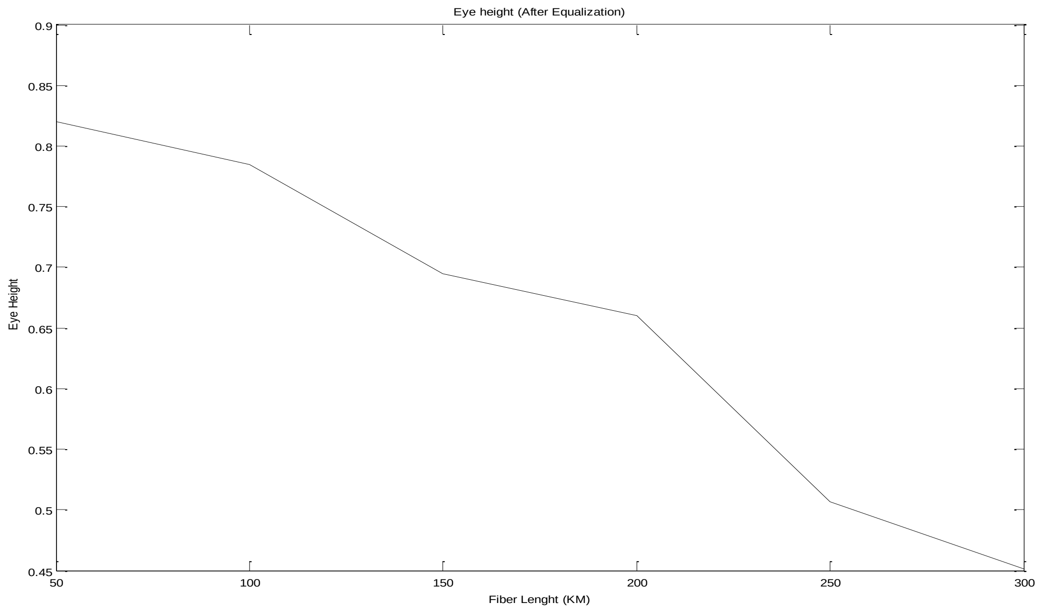

Fig. 10: Graph of Eye Height Vs Length of Fiber after equalization

Analysis of the effect of adaptive equalizer on the eye heigth after equalization

The open degree of eye diagram increased by more than 50% even as the fiber length increases as shown in Fig. 10

V. Discussions

The paper compared the results of the simulations performed to evaluate the effect of adaptive equalizer on nonlinear optic fiber signal in optical network. This was done by comparing the simulation results of the three key performance indicators (the Q factor, the BER and the eye height) with and without the presence of adaptive equalizer algorithm.

Discussion on the effect of adaptive equalizer on the Q factor of a nonlinear signal of an optic fiber network

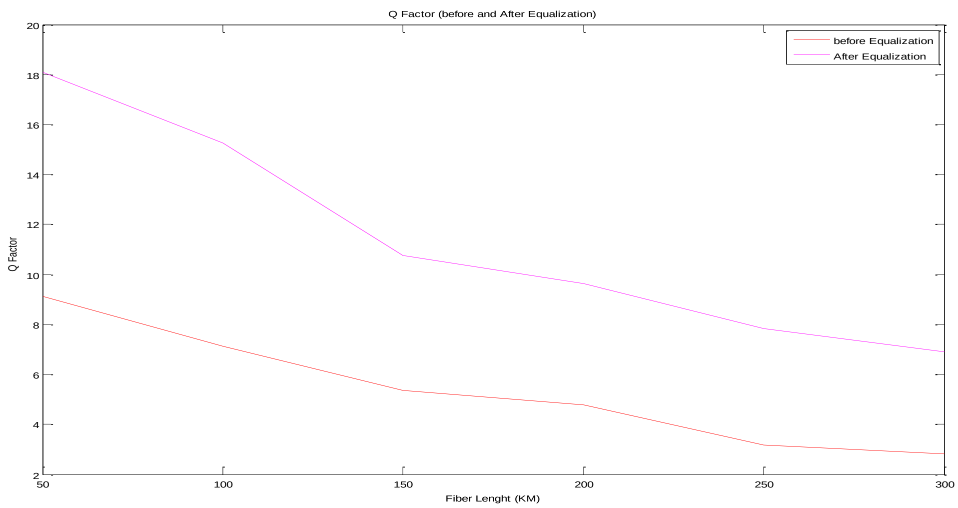

Fig. 11: Comparison Graph of Q factor Vs Length of Fiber before and after equalization

Fig. 11 shows that with adaptive equalizer in the system, the signal quality and the eye's shape are far better. The Q-factor is also bigger, and the corresponding BER is smaller when compared with the condition where the adaptive equalizer algorithm was not used in the model.

Discussion on the effect of adaptive equalizer on the BER of a nonlinear signal of an optic fiber network

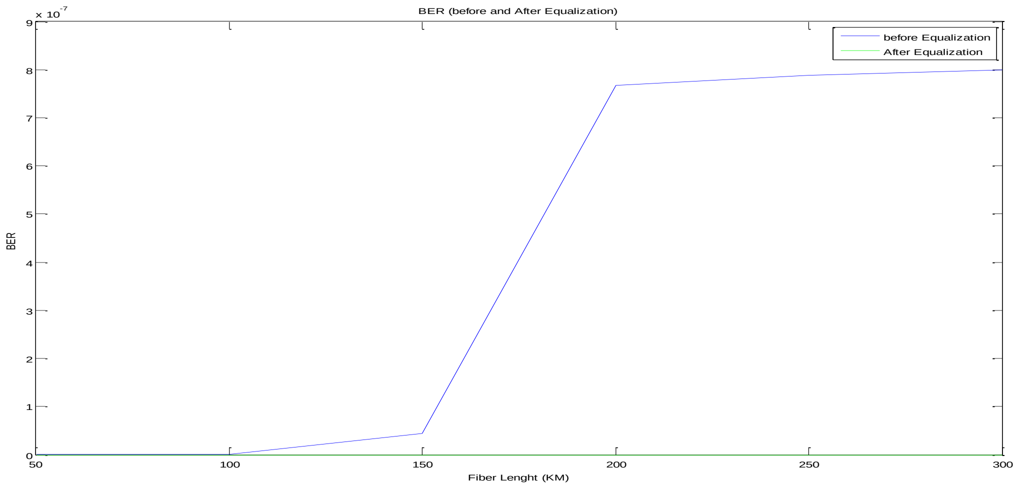

Fig. 12: Comparison Graph of BER Vs Length of Fiber before and after equalization

Bit error rate as a function of distance is an effective way to show the degradation of the transmission quality as the distance travelled by the signal increases. Fig. 12 shows a drastic reduction in BER when the two measurements were compared. The adaptive equalizer algorithm was able to reduce the BER by more than 50% and this will make the packet drop probability to reduce.

Discussion on the effect of adaptive equalizer on the eye height of a nonlinear signal of in optic fiber network

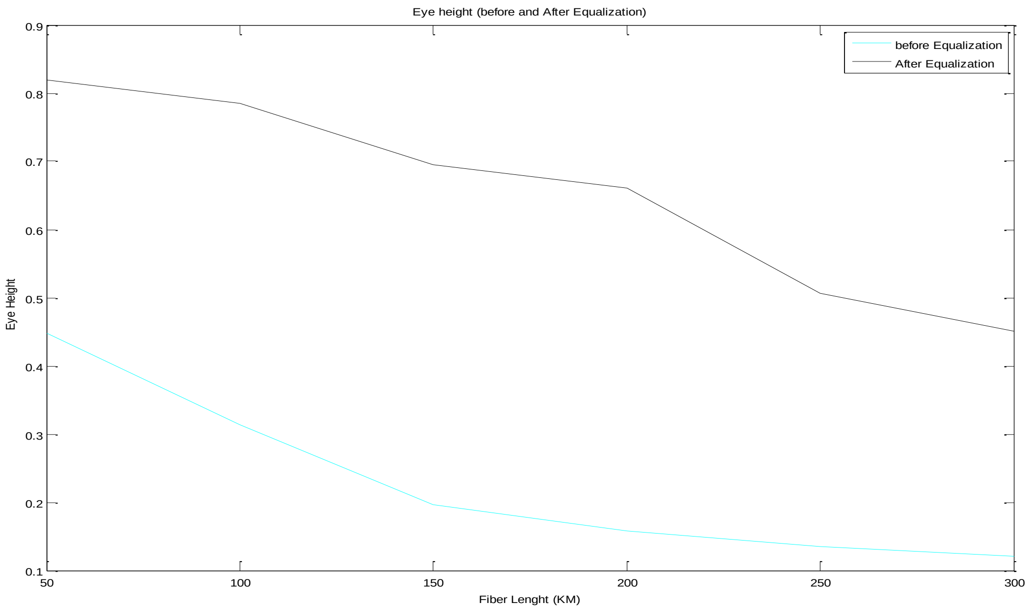

Fig. 13: Comparison Graph of Eye Height Vs Length of Fiber before and after equalization

From Fig. 13 it can be seen that there is more than 50% increase in open degree of eye diagram when adaptive equalization algorithm was applied to the model than when it was not used. This will make the BER to reduce and improve the quality of the received signal with a multiplier effect on the network parameters.

VI. Conclusion

The equalization algorithm used to study the effect of equalization on a nonlinear optic fiber signal for the three key performance indicators viz the Q factor, the BER and the eye height shows clearly that adaptive equalization has a tremendous improvement in mitigating the effect of nonlinear signal on optic network performance showing that an adaptive equalizer can be deployed to effectively reduce nonlinearity effect on optical networks.

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