Effect of Chaos and Instability of Brillouin-Active Fiber Based on Optical Communication

Keong-Tae Yeom[**] · Kwan-Kyu Kim[*] · Ji-Hyoung Kim[**] · Yong-Kab Kim[***]

ABSTRACT

In this paper the effect of instability and chaos in optical fiber networks based on the Internet is described. Nonlinear optical fiber effect especially Brillouin scattering in networks has emerged as the essential means for the construction of active optical devices used for all-optic in-line switching, channel selection, amplification, oscillation in optical communications and a host of other applications. The inherent optical feedback by the back-scattered Stokes wave in optical networks also leads to instabilities in the form of optical chaos. This paradigm of optical chaos in fiber Internet serves as a test for fundamental study of chaos and its suppression and exploitation in practical application in optical fiber communication. This paper attempts to present a survey and some of our research findings on the nature of Brillouin chaotic effect on Internet based optical communication.

Keywords

Internet and Fiber Optics, Optical Communications, Nonlinear Effect, Chaos and Instability

1. Introduction

The Internet is the fastest growing technology on the Earth today, and this is mainly possible because of fiber optics, the hair-thin glass wires that carry laser light communication signals around the globe. Fiber optics is thus a very important technology to the Internet. Our future depends upon the effectiveness of this fiber communication on the Internet, through the installation of optical networks, and advances in the fiber optic technology [1-3].

Important advances have been made in the purity of the fibers them selves ,so the light signal can travel as far as thousands of kilometers without being amplified. However, current electrical and optical amplifiers still institute lossy interfaces that back scattered incident light signal. Large input signals are thus required and these lead to nonlinear optical phenomenon in optical fibers. If the input power into fiber exceeds the some critical threshold level, then a nonlinear effect can occur, which may be converted into reflected light wave, traveling backwards towards the transmitter. The theoretical and physical background of this nonlinear process is provided to describe its nonlinear effect in optical communication/networks [4-5]. The combination of nonlinearity and optical feedback in networks, is a prescription for inherent deterministic instabilities that may ultimately lead to optical chaos in fiber optic Internet [6].

Many computers on the Internet are connected via

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optical fibers to support the optoelectronic communications, digital transmission, file transport protocol (FTP) access, etc for interactive exchange of information/data between computers. The networks are used to connect computers for purposes of resource and file sharing as well as optoelectronic communications [7-8]. In this paper the effect of nonlinear limitations on the fiber networks, in the form of instability and chaos on the Internet are described.

2. Nonlinear effect in optical fiber

It is well known that optical fibers have potential for various uses in the optical communications field [7-11]. Research in the past, and in recent years has focused on using optical fibers as networks each fiber capable of reacting and measuring changes in its immediate environment. Nonlinear optics especially Brillouin scattering in fibers has been extensively demonstrated at very low laser power levels. This made possible fiber optic devices for optical fiber communication, optical signal processing, and optical switching.

The nonlinearity most readily present in the optical fiber is Brillouin scattering and the Kerr effect. Brillouin scattering is light reflection by laser induced acoustic wave in the fiber. Brillouin activity in singlemode fibers has been extensively investigated theoretically and experimentally by many others and us[12-17]. The backward scattering nature of Brillouin scattering has long been viewed as an ultimate intrinsic loss mechanism in long haul fibers, since Brillouin threshold decreases with increasing effective fiber length. On the other hand, the very backscattering nature of this process and the existence of a threshold, provide potential optical device functions, such as optical switching, channel selection, amplification, sensing, arithmetic and neural functions in networks. The backward scattering scheme in optical networks is shown in Fig.1.

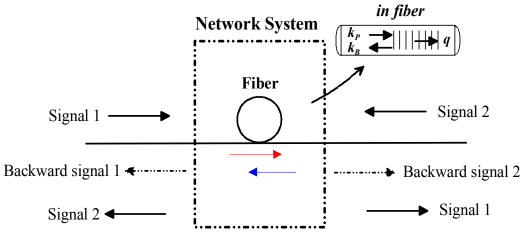

Fig.1. Configuration of the optical network with counter-propagation Stokes signals.

Brillouin scattering has the lowest threshold among nonlinear optic phenomena and hence has attracted the greatest interest in small core, low loss single mode fibers for next-generation communication networks. It turns out Brillouin scattering is a paradigm in the field of nonlinear dynamics in any networks, in which a signal originating from noise evolves into deterministic dynamical behavior through a nonlinear interaction.

The question is whether the originating noises have any effect on the evolved dynamics. This is a fundamental question in the field of nonlinear optical phenomenon in a network system, in which many interactions originate from stochastic processes, the sources of which are either thermal fluctuation or quantum noise.

If the optical power (video-on-demand central office) launched into the fiber coding line exceeds some critical threshold level, then Brillouin effect can occur. The Brillouin effect causes a significant proportion of the optical power traveling through the fiber transmission line to be converted into a reflected light wave, shifted in frequency, traveling backward direction.

The Brillouin effect can occur in a single pass through long fibers of low loss single mode fiber with launched power levels only a few milliwatt, which is within the envisaged operating range of communication systems.

This effect can be detrimental to an optical communications system in a number of ways: severe additional signal attenuation, by causing multiple frequency shifts in some cases, and high intensity backward coupling in the transmission optics. The characteristics of backward Brillouin scattering in fiber (=), such as frequency shift, linewidth, gain, and threshold can be established using same approach as that for a bulk materials. A typical optical spectrum of the backscattered signal in Brillouin shift, showing a narrow single-frequency output with a linewidth of less than 20 MHz. Recently, in our experimental setup, the continuous-wave single-pass Brillouin effect has been observed in low loss single-mode optical fibers of lengths, varying from a few kilometer to 10 meter [13].

Fiber ring configurations greatly reduce the fiber length required [4,12]. The main advantage of the fiber ring lies in the recurrent geometry, in which the backscattered (Brillouin) wave is repeatedly amplified by the incoming pump wave at the input port that is not attenuated by fiber loss, as opposed to the linear fiber amplifier, in which the backscattered (Brilllouin) wave encounters a progressively depleted forward traveling pump wave. The Brillouin active ring is governed by the finesse and the nonlinear Brillouin scattering phenomenon in the fiber. Its enhanced finesse is clearly demonstrated in the form of line narrowing [12]. It is to be noted, since Brillouin scattering is a backscattering process, there is a threshold g = g0P0L/A = 21 for a straight fiber, and is lowered in a fiber-ring to 0.1 [4].

3. Brillouin chaotic effect

3.1. Brillouin fiber instability

An active device in network systems in general requires the employment of nonlinearity, and possibly feedback for increased efficiency in device function. However, the presence of nonlinearity together with intrinsic delayed feedback has been repeatedly demonstrated to lead to instabilities and ultimate optical chaos. Instabilities are unavoidable in Brillouin scattering due to its intrinsic nonlinearity and feedback. Our effort is then to exploit device function and suppress instabilities by simulation, design for optimization on the one hand, and the promotion of such deterministic instabilities on the other for novel data transmission in optical communications.

We have designed a setup for analyzing Brillouin instabilities in a fiber-ring configuration. The main advantage of fiber-ring has already been given above. A schematic of the setup for analyzing chaos is shown in Fig. 2. Some level of temporal instability and chaotic behavior in the backscattered intensity and also in its spectral line shift will be observed.

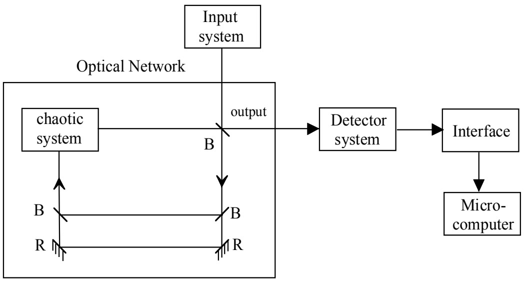

Fig.2. Schematic diagram of experimental arrangement for controlling chaos in optical system.

It is thus essential whether such an amplifier will further destabilize optical networks. Since our proposed fiber ring sensor is based on monitoring the Brillouin spectral line shift with varying temperature and strain [13], the origin of the temporal chaotic behavior must be understood and its correlation to spectral line shift examined. The Brillouin line is further analyzed with a spectrum analyzer, which permits better resolution of the fine structure of the Brillouin line, and also on a fast scope for better interpretation of the process that leads to pulse generation. The detected signal will also be viewed on a Microcomputer for comparison.

The backward signal is detected with a fast detector as the laser pump power is progressively increased to maximum of 16mw. When the pump power reaches a threshold value, a temporal structure arises in the backward signal, consisting of a periodic train of Brillouin-wave pulses as shown in Fig. 3(a). The temporal repetition rate of which corresponds to a pulse round-trip time in the fiber-ring taken to be less than 10 nsec. The peak pulse amplitude of the wave remains unstable, particularly just below pump threshold. When the observation is made using a long time scale (100 sec/division), the Brillouin output exhibits randomly distributed trains of periodic pulses.

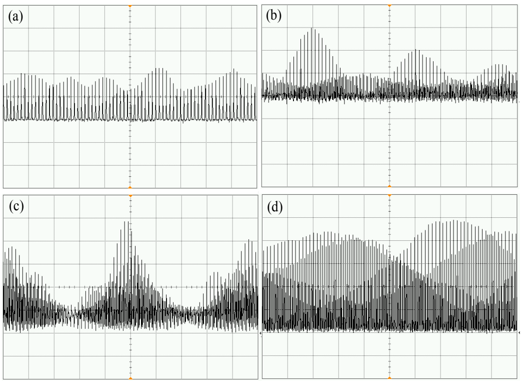

Fig.3. Temporal structures of Brillouin fiber instability
vs time in a LITESPEC G ZEANQ2 Fiber.

Partial stabilization of amplitude fluctuations is achieved as laser pump power approaching maximum value. These experimental features are shown in Fig. 3(b-d) as a function of time. In the data predicted mechanical vibrations could be partially responsible for these Brillouin-temporal instabilities, because small amplitude fluctuations with similar frequencies were observed below the Brillouin threshold as compared to our numerical results [13]. The results attribute these Brillouin instabilities to phase fluctuations between direct and coupled pump intensity in the fiber-networks.

We know that one of the simplest processes in nonlinear optics is the mutual interaction of two light waves in a nonlinear medium. Despite its conceptual simplicity, several recent theoretical investigations have shown that this interaction can lead to very complicated behavior, including chaotic fluctuations of the intensities. It has been shown theoretically that for a variety of nonlinear interactions the intensities of the waves can become unstable in the form of growing temporal fluctuations and that under certain circumstances. These instabilities can be chaotic in nature [14-15]. The Brillouin instability was also considered for the case of an optical fiber with a Kerr nonlinearity having a non-instantaneous response in communication networks [15].

3.2. Proposed chaos control

The possibility of controlling chaos using periodic pulse train has recently stimulated much theoretical analysis [16-17]. The principalidea is the stabilization of unstable periodic waves using a chaos suppressor and bandpass filtering. Since these proposed systems are very effective as suppressor and controlled filter in digital networks, a successful controller may also serve as a generator (possibility as encoding/decoding message) of rich forms of periodic waves, thus turning the presence of chaos to advantage. We propose to employ continuous optical feedback for the control in which coherent interference of the chaotic optical signal with itself, when delayed, is used in achieving signal differencing for feedback (see Fig.2). Much work needs to be done to test this theory. If successful, we will then be able to perform encoding/decoding of messages in real time Internet communications. In the communications/Internet site, the power supply for the computer is used as a network server, timing the login onto the transmission line. The site receives the information from the local computer at the center, and downloads the nonlinear effect files.

4. Conclusion

We have demonstrated that Brillouin scattered waves in a fiber used in optic communications are temporally unstable above certain threshold intensity. We have also shown how the threshold for the onset of instability varies as a function of the ratio between the input signal intensities for various values of the Brillouin output in networks. To determine the full dynamic behavior of the networks with instabilities, we have integrated the coupled nonlinear equations in time by using the method of characteristic. It is theoretically possible to apply the multi-stability regimes as an optical memory device for encoding/decoding messages and complex data transmission in the optic communications/networks.

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