SUBOPTIC Bangkok | 2023

DETECTING LINK ANOMALIES CAUSED BY PHYSICAL MOVEMENTS OF PATCH-CABLES, USING STATE OF POLARIZATION MONITORING

Aamir Gulistan (Simula MET) Steinar Bjørnstad (Tampnet AS)
Simulamet, Pilestredet 52, Oslo, Norway, Tampnet AS, Stavanger, Norway, aamir@simula.no, steinar@simula.no

Abstract: In this paper, we explore a novel technique for the detection and distinction of unexpected movements of patch cables in optical fiber networks by utilizing State of Polarization (SoP) analysis. The method employs an SoP analyzer installed at the receiver end of the optical fiber communication system to detect changes in the SoP of the light transmitted through the fiber. Through a series of experiments, we investigate the SoP sensitivity to various frequencies of movement, enabling the distinction of direct movements induced by manual movements of the fibre-cord, and indirect movements, arising from environmental vibrations. The motivation is monitoring for the purpose of ensuring integrity of the network. The results of the study demonstrate the capability of this approach in the detection and prevention of link outages in optical fiber networks.

1. INTRODUCTION

Optical fiber networks are used for high-speed data transmission, but their reliability can be compromised if there are unexpected movements of the fibers or patch cables. These movements can be caused by tampering or eavesdropping attempts, or simply by vibrations from the environment. Unexpected movements of fibers or patch cables can result in link outages, bit errors, and other issues that can affect the performance of the network. It is therefore important to be able to detect and warn of such movements in order to maintain the reliability of the network.

One approach to detecting movements of patch cables in optical fiber networks is to use Distributed Acoustic Sensing (DAS) [1]. This technique relies on the detection of phase delays caused by Rayleigh backscattering in a dedicated fiber or wavelength, and has been demonstrated to be effective in distinguishing different acoustic wave modes based on their propagation speeds. However, the use of DAS can be complicated by the need for a dedicated fiber or wavelength, which may not be practical in all situations.

Another approach that has been proposed is the use of State of Polarization (SoP) detection for the preventive protection of optical links [2,3]. SoP refers to the orientation of the electric field vector of light within a fiber, and changes in SoP can be detected using a simplified detector [2]. By monitoring changes in SoP, it is possible to detect movements of patch cables that may be caused by tampering or other anomalies. In one study, it was demonstrated that a 2.5 Gb/s PRBS (pseudorandom binary sequence) stream of data could be protected by switching to an alternative path in the event of SoP changes, with only a few bits of data being lost [3].

There are also several techniques that use fiber optic sensors to detect movements of patch cables in optical fiber networks. These techniques are based on various principles such as SoP modulation [4-6], phase-sensitive detection [7,8], and intensity modulation [9]. For example, Lu et al. [4] propose a fiber optic displacement measurement system based on SoP modulation, while Chen et al. [7] describe a fiber-optic displacement sensing system based on phase-sensitive detection. These approaches may be useful for detecting and warning of anomalies in optical fiber networks.

In addition, data from coherent optical receivers and machine learning techniques can be used to proactively detect and warn of events that may cause fiber breaks [10]. By analyzing data from the coherent optical receivers in real-time, it is possible to identify patterns or trends that may indicate an imminent fiber break. This can allow network operators to take proactive measures to prevent outages or other issues.

In this paper, we propose a method for detecting movements of patch cables in an optical fiber network using a simplified SoP analyzer. The SoP analyzer is installed at the receiver end of the optical fiber using SFP (small form-factor pluggable) transceivers and is used to detect changes in the SoP of the light transmitted through the fiber. We focus on the Gigabit Ethernet (GbE) bitrate, which is commonly used in access and metro networks, but our approach could also be applied to higher bitrates used in transport networks.

To characterize the sensitivity of the SoP analyzer to different frequencies of movements, we conduct experiments in which we induce both direct and indirect movements of the patch cables. Direct movements are those caused by tools or hands, while indirect movements are those caused by vibrations picked up from the environment. Our goal is to determine if direct movements can be distinguished from indirect movements using the SoP analyzer. To this end, we analyze the frequency and sensitivity of the SoP variations for both types of movements.
In addition, we use an air gun to simulate a rapid movement of the patch cable. The air gun is fired without a pellet, causing a rapid movement of the patch cable due to the directed air flow from the tip of the barrel. This allows us to characterize the expected amplitude and highest frequency of a direct movement, and to determine how well the SoP analyzer can detect such movements.

Overall, our goal is to develop a low-cost method for detecting and warning of anomalies in optical fiber networks using a simplified SoP analyzer. By detecting movements of patch cables, network operators can be alerted to potential issues such as tampering or eavesdropping attempts and can take proactive measures to protect

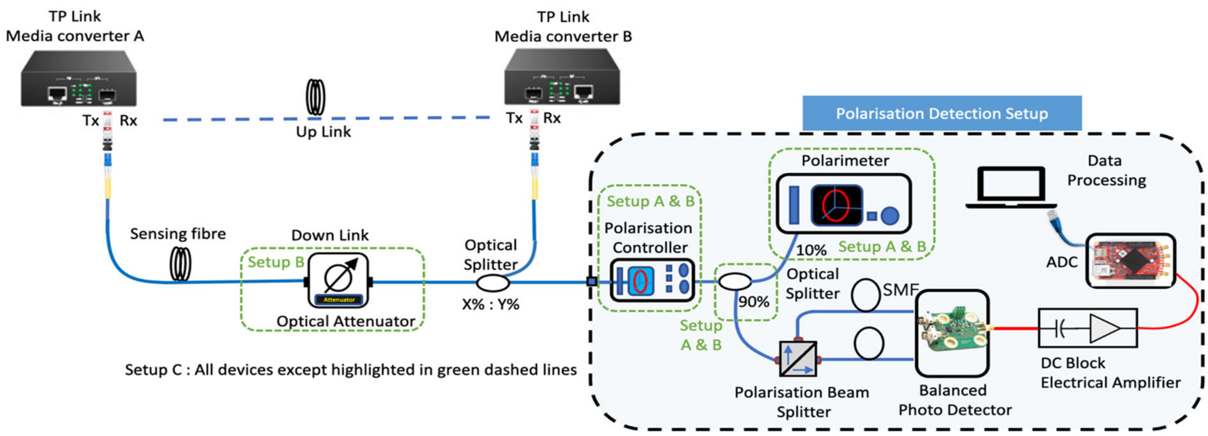

Figure 1: Experimental setup for the three different experiments. A is for characterizing the frequency response and B is the receiver sensitivity of indirectly induced vibrations (X=Y= 50% splitter). Experiment C characterizes a direct movement of the fiber (X=10% to receive, Y = 90% split to PBS. The polarimeter is for reference testing only.

the network and maintain its reliability. Our experiments with both direct and indirect movements of the patch cables allow us to understand the sensitivity of the SoP analyzer to different frequencies of movements, and to determine the feasibility of using this approach for detecting anomalies in optical fiber networks.

2. EXPERIMENTAL SETUP

The experimental setup is shown in figure 1. Internet traffic is transported between two GbE TP link media converters (MC) MC220L using SFP transceivers Finisar FTR J1522P1BTL (80 Km, 1550 nm, non-WDM). The electrical side of the first MC is connected to the GbE port on a laptop and the second to a GbE port on a switch connected to the Internet, putting the system in operation and verifying the transmission capability. The optical sides of the MCs are connected through a patch cable for the return path while monitoring is performed on the downstream path where a fraction of the signal passing through the optical transmission system is tapped off using an optical coupler.

The first experiment characterizes the sensitivity to vibrations for the receiver. Vibrations are induced on a standard G.652 fiber cord by a SEAS FA22RCZ wide-bandwidth loudspeaker fed with an audio tone variable from 20 Hz – 20 kHz. The configuration sends the signal through the fiber cord tapered to the floor and passing 2.5 cm below the center of a loudspeaker covering 22 cm length of the fiber cord used as the sensing fiber. When characterizing the receiver sensitivity, setup B, a variable attenuator is applied, adjusting the input power to the PBS. The signal is then 50/50 % split to a SoP controller (SoPc) and an MC respectively. The signal from the SoPc is then split 10/90 % with 10% to a Thorlabs PAN 9300 module in a PAT 900B polarimeter, and 90 % to the simplified SoP analyzer consisting of a Polarization Beam Splitter (PBS) where the two output legs are terminated in a differential optical detector. The differential signal from the polarization detector will miss certain polarization events and detect too low Polarization Rotation Rates (PR) [2]. The SoPc before the PBS is therefore set to maximize the sensitivity of the SoP receiver during the indirect induced vibration experiments A and B, and the output of the detector is fed through a DC block and amplified 10 times before entering the AD converter for analysis in time and frequency domain. Experiment A characterizes sensitivity to indirectly induced vibrations of different frequencies induced through the loudspeaker while in experiment C direct movements are explored by hitting the patch-cord with the air-flow from an air-gun fired at different distances to a patch-cord hanging vertically from a tripod.

3. RESULTS AND DISCUSSION

In the indirectly induced vibration experiments frequencies up to 2500 Hz was detected as this was the maximum frequency detected with a sufficient signal to noise ratio. No impact from noise induced by the GbE transmission system was observed. The lowest frequency induced was 20 Hz, as this was the lower threshold frequency of the audio amplifier and loudspeaker. The highest sensitivity is found for the lowest frequencies. In experiment B, by varying the optical input power to the PBS, the sensitivity of the receiver when inducing a 25 Hz audio tone of 1.1 W loudspeaker power, the sound pressure of 86.45 dB, is characterized. Because the simplified detector does not provide an accurate measure of PR [2], change in SOP (SOPC) measurements in all experiments are relative and the differential output voltage values from the detector in experiments A and B are normalized according to the optical input power in experiment C, and then applied as a measure of the SOPC. For the lowest detectable SOPC, the input power is -34.4 dBm, while the highest SOPC measured is for -22.52 dBm. Results are shown in figure 2. The sensitivity to vibrations of different audio frequencies is then characterized by setting the audio signal power to 1.1 W, and optical input power to the PBS to -13 dBm. The audio-signal frequency is then varied from 20 Hz to 2500 Hz. The results are shown in figure 2. The highest sensitivity is found for the lowest frequencies (25 Hz), decreasing rapidly to 400 Hz, where the decrease slows down. Results show that when vibrations are transferred mechanically to the patch-cord from a firm material, low frequency vibrations may be detected with high sensitivity with maximum sensitivity for the lowest frequency of 20 Hz.

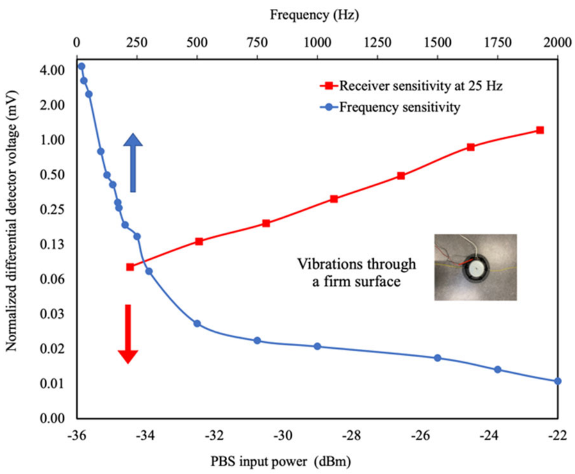

Figure 2: SOPC as a function of received optical power, for experiment B. For experiment A, SOPC as a function of induced vibration frequency for a fiber on the floor is shown.

In experiment C optical input power was -9.7 dBm. Figure 3 shows SOPC caused by 1 to 5.5 cm displacements of a fiber, caused by the directed air gun air-flow when firing at distances of 0 to 10 cm (illustrated in figure 4), demonstrating a repeatable and similar pattern for the different distances. The shortest rise-time (10-90%) corresponding to 4.5 ms and a bandwidth of 222 Hz is for the first transient corresponding to 5.5 cm displacement. The smallest SOPC, for 1 cm displacement, shows a SOPC value of approximately one-fourth of the value for 5.5 cm displacement. Comparing SOPC of direct displacement with the SOPC caused by indirect vibration from the loudspeaker shows comparable values only for the lowest frequencies of 20 to 50 Hz. For indirectly induced vibrations with frequencies beyond 100 Hz, the SOPC is lower also for the moderate displacement of 1 cm.

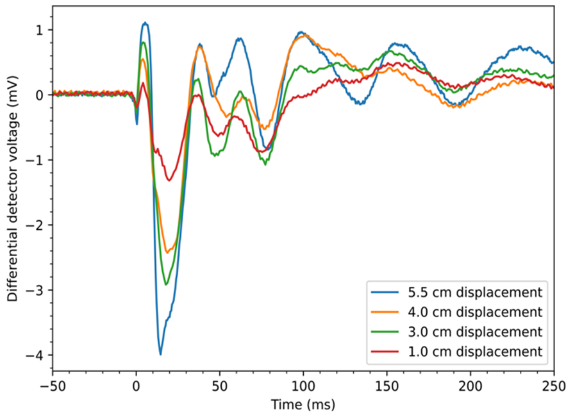

Figure 3: SOPC as a function of time for different displacements of the fiber-cord hit by the air gun air-flow from different distances.

Figure 4: Barrel of air-gun pointing at fiber. The Air-gun is fired from different distances without a pellet (air-pressure only).

4. CONCLUSION

In this paper we have monitored SOP variations and characterized the sensitivity detecting vibrations at different frequencies induced in a patch-cord from the environment, comparing with direct displacements of the fiber-cord. Monitoring of SOP variations is performed using a simplified polarization analyzer added to a commercial optical transmission system, monitoring while transferring data. We conclude that movements causing displacements of patch-cords may be distinguished from indirect vibrations because direct movements typically cause a larger SOPC, especially for frequencies beyond 100 Hz where the sensitivity to indirectly induced vibrations decreases rapidly. Directing the air-flow from an air-gun while firing created a fast SOPC of 4.5 ms rise-time that indicates a maximum required detection bandwidth of approximately 250 Hz. The detection of unexpected movements can be applied for issuing alarms and proactive protection switching.

5. REFERENCES

[1]. E. Ronnekleiv et al., "Distributed Acoustic Sensing for submarine cable protection," Suboptic 2019, available online at: https://suboptic2019.com/download/5044/

[2]. J. E. Simsarian and P. J. Winzer, "Shake before break: Per-span fiber sensing with in-line polarization monitoring," 2017 Optical Fibre Communications Conference and Exhibition (OFC)

[3]. S. Bjornstad, M. Nord, and D. R. Hjelme, "Transparent optical protection switching scheme based on detection of polarisation fluctuations," Optical Fiber Communication Conference and Exhibit (OFC), 2002

[4]. F. Boitier, "Proactive Fiber Damage Detection in Real-time Coherent Receiver," in 2017 European Conference on Optical Communication (ECOC), (2017), 1, pp. 2–4.

[5]. M. O. Alqahtani, Y. A. Elsayed, and M. M. El-Gohary, "Real-time fiber optic sensing system for the detection of vibration-induced fiber displacement," Optik - International Journal for Light and Electron Optics, vol. 125, no. 20, pp. 5987-5994, 2014.

[6]. X. L. Lu, Y. L. Wang, and H. Zhang, "Optical fiber displacement measurement based on state of polarization modulation," Optics Communications, vol. 393, pp. 60-66, 2017.

[7]. S. Chen, L. Liu, J. Yu, and Y. Chen, "A fiber-optic displacement sensing system based on phase-sensitive detection," Measurement Science and Technology, vol. 27, no. 7, 2016.

[8]. Y. Zhang, X. Wang, and J. Hu, "Displacement measurement based on the phase-sensitive detection of optical frequency domain reflectometry," Measurement Science and Technology, vol. 29, no. 6, 2018.

[9]. L. Ren, J. Zhang, and L. Zhang, "A fiber-optic displacement sensor based on a phase-sensitive amplifier and an intensity modulator," Measurement Science and Technology, vol. 27, no. 7, 2016.

[10]. S. R. Chaudhary, S. A. K. Bhat, and S. K. Koul, "Fiber optic temperature and strain sensor using two fiber Bragg gratings and polarization maintaining fiber," Measurement, vol. 45, pp. 1056-1065, 2012.

