Perimeter Intrusion Detection with Backscattering Enhanced Fiber Using Telecom Cables as Sensing Backhaul

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Abstract: We report field test results of facility perimeter intrusion detection with distributed-fiber-sensing technology and backscattering-enhanced-fiber by using deployed telecom fiber cables as sensing backhaul. Various intrusive activities, such as walking/jumping at >100ft distance, are detected.

1. Introduction

Telecom carriers have built large-scale fiber infrastructure to support Internet traffic growth [1]. Employing telecom fiber as sensing media by using distributed fiber optic sensing (DFOS) has been reported in traffic monitoring [2], vibration detection and localization [3], and cable threat assessment [4]. Following the rapid growth in deployed fiber infrastructure, there is increasing demand to use the same cable for facility perimeter security. A critical task for any business, agency, or government is the protection of its property and other assets. There are many solutions used in perimeter security detection such as video motion detection [5], active infrared detectors [6], microwave and wireless detectors [7], high-voltage pulse electric fences, quasi-distributed FBG networks [8], etc. However, there are some shortcomings in all systems such as difficulty to localize and classify intrusions accurately. In addition, for wireless sensor networks, a huge number of point sensors are required which increase the operation and maintenance costs from carriers. A new way to increase the value of carriers' fiber is using telecom cables as sensing backhaul. While deployed telecom fiber cables are able to perform most fiber optic sensing tasks, a hybrid architecture, telecom fiber cables plus specially designed fiber with higher sensing sensitivity, can further enhance the performance. In this paper, we take advantages of both telecom fiber and sensing-enhanced fiber and report the application of perimeter intrusion

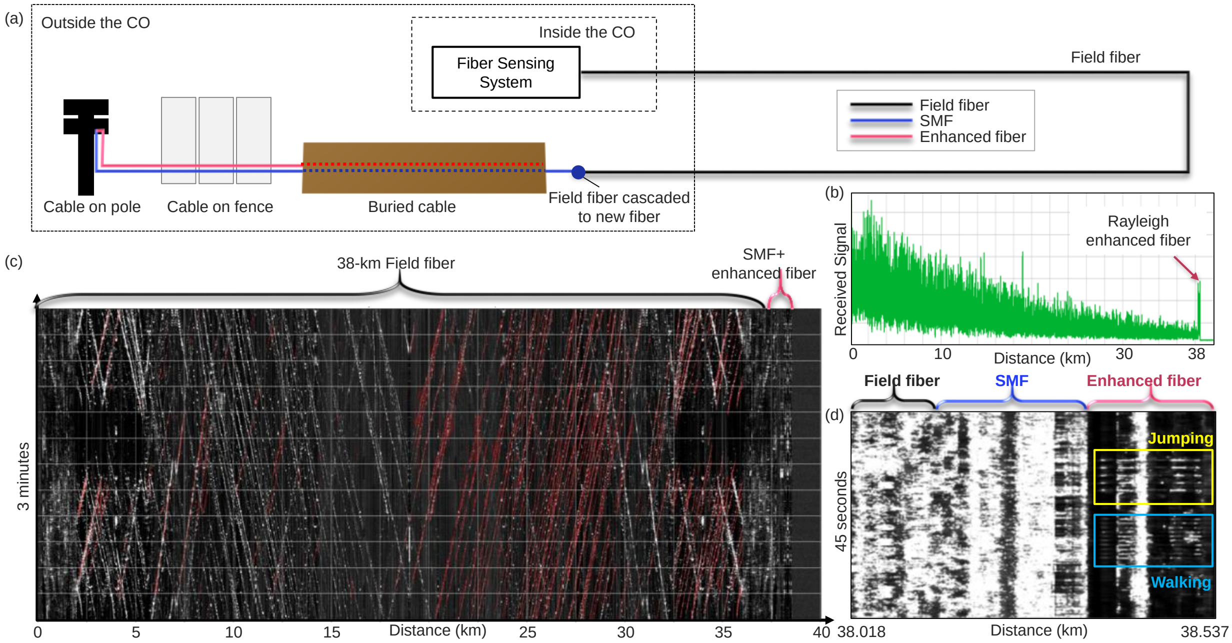
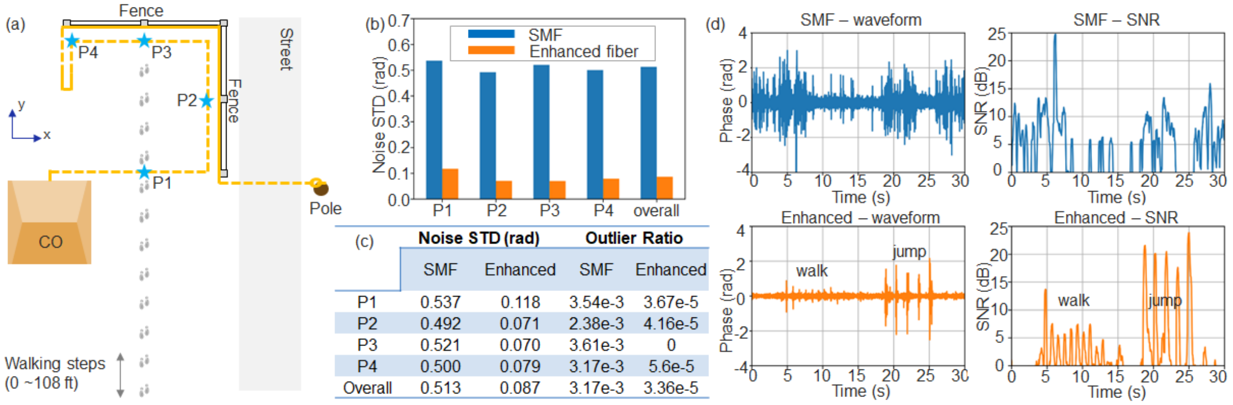


Figure 1: (a) System setup. (b) Received backscattering signals. (c) Received waterfall trace from the fiber sensing system over 38-km field fiber. (d) Enlarged waterfall trace for facility intrusion detection.

detection by using telecom facility as sensing backhaul. A recently developed fiber with enhanced backscattering is simply integrated into existing telecom networks to expand sensing functions by DFOS technologies. It can be installed surrounding the building to detect various intrusive activities such as people walking/jumping, fence shaking/kicking, and pole climbing. Reporting these events instantaneously can allow quick action to be taken, preventing potential damage to properties of the facility.



(c)

	Noise STD (rad)		**Outlier Ratio**	
	SMF	Enhanced	SMF	Enhanced
P1	0.537	0.118	3.54e-3	3.67e-5
P2	0.492	0.071	2.38e-3	4.16e-5
P3	0.521	0.070	3.61e-3	0
P4	0.500	0.079	3.17e-3	5.6e-5
Overall	0.513	0.087	3.17e-3	3.36e-5

Figure 2: (a) Top view of the walking/jumping detection at a central office (CO). (b) Comparison of standard deviation (STD) of noise between the SMF and backscattering -enhanced fiber. (c) Detailed results of the noise STD and the outlier ratio. (d) Waveform and SNR of SMF and enhanced fiber at position P3, respectively. A person was walking and jumping 30-ft away from P3.

2. System Setup and Field Test Results

The field trial was conducted over a carrier's network in Long Beach Island, NJ, USA. Fig. 1(a) shows the configuration consisting of a sensing system inside the remote terminal, 38 km of standard field fiber, and a hybrid SMF/backscattering-enhanced fiber cable adjacent to the terminal. One distributed acoustic sensing (DAS) system was used and placed at a remote site. The remote terminal is becoming a sensing backhaul with existing fiber for environmental monitoring such as road traffic, and then cascaded to an upgraded sensing branch for new applications such as perimeter intrusion detection. The 38-km field cable is a loop-back fiber between two remote terminals buried at 40–60-inch depth. Hence, the waterfall trace in Fig. 1(c) shows the symmetric road traffic patterns. After 38-km fiber, a hybrid SMF/backscatter-enhanced fiber cable is connected to the field fiber and installed outside of the terminal. There are three sections of the cable installation, including buried underground, attached to the fence, and lashed to the pole. The backscattering-enhanced AcoustiSens® fiber is UV processed to provide a continuous, order-of-magnitude increase in backscattering over standard fiber [9,10]. The attenuation of the enhanced fiber is 0.5dB/km. Fig. 1(b) shows the received backscattered signals from the DAS. It can be seen that the signal-to-noise (SNR) was improved by the backscatter-enhanced fiber after transmission through 38-km of standard fiber (~12.5 dB total loss included connection loss inside terminals). Fig. 1(d) presents the enlarged waterfall trace section of hybrid SMF/enhanced fiber. Due to the low SNR of SMF sections, it is difficult to identify intrusion signals and noise at the distance sections. However, people walking and jumping can be seen clearly using the enhanced fiber.

To quantitatively investigate the sensing performance, we collected sensing signals from both SMF and the backscattering-enhanced fiber at four positions (P1, P2, P3, and P4) as shown in Fig. 2(a). Fig. 2(b) illustrates the standard deviation (STD) of noise and the corresponding results are given in Fig. 2(c). The noise STD of the SMF varies from 0.492 to 0.537, while the enhanced fiber has an averaged noise STD of 0.087, highlighting a noise reduction factor of around 5.9. It is noted that there are outliers in the demodulated phase due to the low signal amplitude or the fading effect. We calculated the ratio of outliers by counting the phase jumps from 1.3×10^7 data samples. Compared to SMF, the enhanced fiber significantly reduces the outlier ratio by two orders of magnitudes. Fig. 2(d) demonstrates the received waveforms and calculated SNRs at position P3 when a person was walking and jumping 30-ft away. The backscattering-enhanced fiber can clearly observe the signals with averaged SNR of 5 dB (walking) and 20 dB (jumping) after 38 km, while the SMF fails to give an explicit indication of the activities.

We then conducted another test to verify the performance at different locations. This time a person walked from 108 ft to 6 ft at the speed of 3.4 ft/s. The waveforms of SMF and enhanced fiber collected at P3 are shown in Fig. 3(a), respectively. The walking signal of SMF was immersed in the large noise, making most of the steps indistinguishable even in the SNR figure. In contrast, the backscattering-enhanced fiber can pick up almost all the steps with an

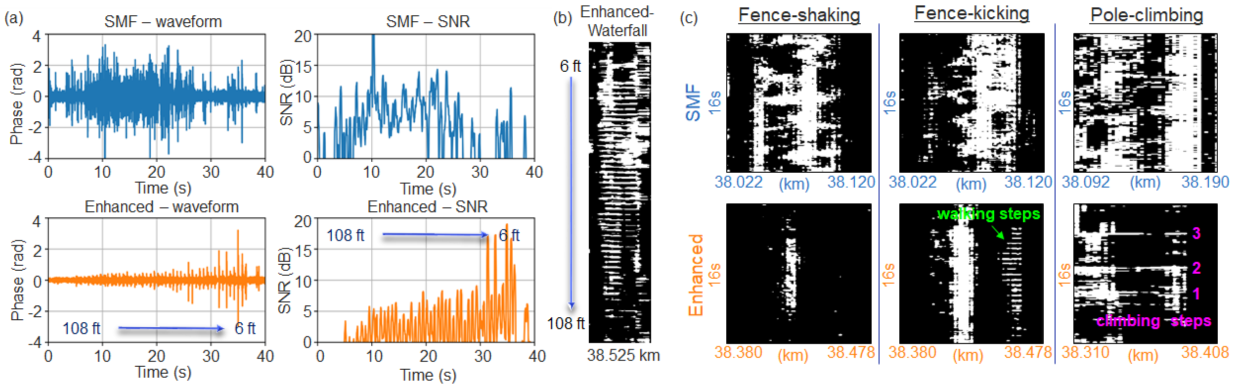


Figure 3: (a) The waveform and SNR of the SMF and enhanced fiber when a person walked from 108 ft to 6 ft from P3 shown in Fig. 2(a). The right image shows the enlarged waterfall of the enhanced fiber part. (b) The enlarged waterfall patterns of SMF and enhanced fiber from various intrusive activities including fence-shaking, fence-kicking, and pole-climbing.

increasing SNR from 1.2 dB to 18.4 dB, which is verified by the enlarged waterfall shown in Fig. 3(b) which can identify every single step from 6 ft to 108 ft perpendicular distance to the cable.

Besides walking and jumping, we also tested other intrusive activities such as shaking, kicking the fence, and climbing the pole. Fig. 3(c) demonstrates the corresponding waterfall patterns of SMF and enhanced fiber on these activities, respectively. It is noted that the windy weather during the experiment caused extra noise on the fence waterfall patterns. However, the enhanced fiber is still able to distinguish the shaking signal, while the SMF gives a barely visible pattern. For the fence-kicking test, both the SMF and enhanced fiber can pick up the impulsive signal transmitted from the fence to the buried cable. However, only the backscattering-enhanced fiber can show a distinct pattern at the fence region as well as walking close to the fence. For the pole-climbing test, the enhanced-fiber pattern markedly pinpoints the three climbing steps on the pole, while the one from SMF hardly gives any clues of the activity. These results highlight the significant improvement of sensing performance by using the backscattering-enhanced fiber after a long distance.

3. Conclusions

We demonstrated the perimeter intrusion detection with new applications of employing deployed telecom cables as sensing backhaul for sensing-sensitivity enhanced fiber. While existing telecom fiber networks can be used for all kinds of environmental sensing applications, backscattering-enhanced fiber is able to provide higher sensitivity, which is particularly useful for detecting intrusive activities at a distant location from the sensing equipment by boosting signal to noise ratios. In this test, people walking/jumping is detected at >100 ft away from the cable with the new fiber. The results show that sensing backhaul architectures can help telecom carriers to offer sensing services of facility security to their customers while protect their own network assets with longer reach distances than the case without using the backscattering-enhanced fiber.

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5. Reference

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