Detecting Physical Impacts by Monitoring State of Polarisation in a Live Fibre-To-The-Home Data-communication Air-Cable

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Abstract: Heavy wind may tear cables down, damaging infrastructure, triggering outage in data-communication networks. We demonstrate local observations of wind in the access-network, monitoring State of Polarisation in a live Fiber-To-The-Home air-cable.

1. Introduction

The digitisation of the society has increased our dependability on data communication and our need for high availability in network connections. Furthermore, using the fibre network not only for communication, but also for sensing of e.g. earthquakes, has been demonstrated [1, 2]. Fibre to the Home (FTTH) and optical backhaul/fronthaul mobile network deployment is steadily increasing, motivating the need for any monitoring that can reveal sources of outage and give early warnings and alarms. Heavy weather conditions is one contributor to network outages in FTTH access networks, especially when deployed using air-cables that may fall down due to weak pole-attachments, heavy wind or trees hitting the cable. Previous works have demonstrated that State of Polarisation (SoP) in transport optical fibre transmission systems is impacted by any vibrations in the fibre-cable, like e.g. wind [3] and strong electromagnetic fields from power cables and lightnings [4]. When monitoring SoP in a transmission system at the receiver end, any change in SoP caused by any event along the fibre-cable will be part of an integrated signal without spatial information. Localising the position of e.g. strong wind-conditions is then possible for the geographical area along the cable. For transport fibre links involving lengths of hundreds of kilometres, this implies a large geographical area. If monitoring shorter cables, like e.g. in the FTTH network, the size of the area will be local and constrained to a few square kilometres. Telecom and data networks have a need for cost-efficiency. Adding any monitoring equipment in the network therefore calls for simplicity and a high integration potential [5]. A comparison between a full Stokes-parameter measurement based polarimeter and a Polarising Beam Splitter (PBS)-based measurement was demonstrated in [5], showing that both types of systems can equally measure and that the PBS-based system was only slightly less sensitive to SoP variations caused by environmental temperature and train vibrations than the full polarisation-state characterisation [5, 6]. In this paper we propose a scalable SoP monitoring infrastructure based on PBS-based monitoring nodes. SoP variations caused by lightning and strong wind is previously demonstrated on long transport fibres along high-voltage power lines [4, 7] over 90 km or more. In this paper we monitor an FTTH air-cable of approximately 2 km length with dense pole attachments (tens of meters) and lower weight per meter compared to fibres spun on top of, or embedded into high-voltage aerial wires. This enables a higher sensitivity to detection of local heavy rain and wind within the geographic area of the approximately 2 km long access network cable. We indicate in this paper which frequencies of SoP variations that may be expected due to thunderstorms, heavy wind and rain, and the duration of these events. In our ongoing field-trial on a FTTH cable with live data-traffic at Bekkestua (Bærum municipality) in Norway, we have so far recorded 11 months of data. In this paper, we focus on the weather conditions occurring during a thunderstorm in the middle of August 2022. To the best of our knowledge, this is the first time SoP monitoring results has been presented for an FTTH air-cable. Results may addditionally be of interest designing future high-bitrate communication access systems where SoP variations must be dealt with in the receiver when decoding polarisation multiplexed modulation formats.

2. Data Collection System Design

For analysing SoP in network infrastructures, we propose a scalable infrastructure based on low-cost, off-the-shelf components [8, 9]. Fig. 1 illustrates the prototype system, consisting of 1-unit rack-mount nodes for simplified SoP monitoring. Each node is equipped with a PBS, separating the optical input signal into two components, based on the SoP of the input. The two optical components are measured by two photodetectors, then AC-coupled

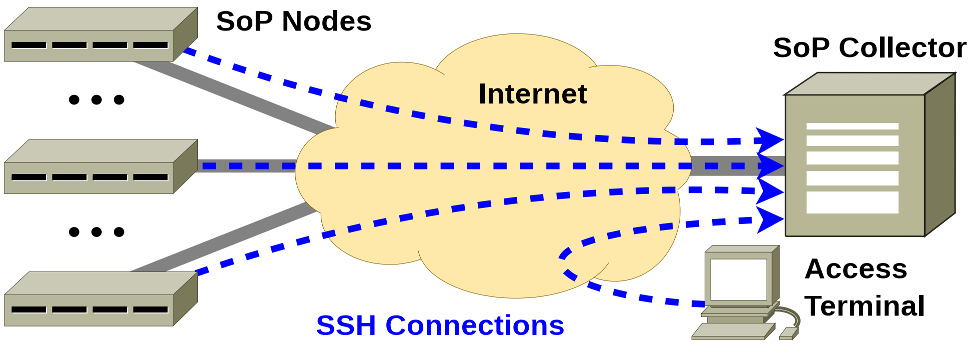

Fig. 1. SoP data collection system.

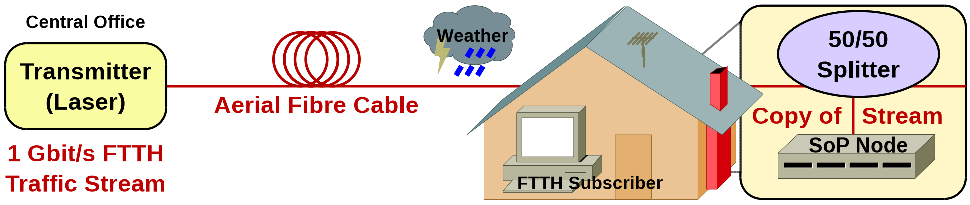

Fig. 2. FTTH Access System Setup

using a first-order high-pass filter with 10 Hz lower frequency, and then digitised by AD converters with a cut-off frequency at 20 kHz. The processing unit of the node then records these data streams in the form of audio signals, which are compressed using Free Lossless Audio Codec (FLAC) [10], and stored onto an internal harddisk. While the harddisk provides storage space for around 1-2 years of collected data files, the files are also regularly synchronised to a central server, denoted as the SoP Collector, via Secure Shell (SSH) connections, to provide long-term storage of all data collected from the measurement infrastructure. From the collector, data are retrieved by access systems for further processing and analysis. The amplitude of the SoP variations heavily depends on the type of cable and infrastructure being monitored. In this system, recorded SoP values are relative, varying between -1 and +1.

3. Experimental Setup and Results

The setup is illustrated in Fig. 2: The SoP monitoring is performed at the subscriber side on an FTTH cable of approximately 2 km length, located in Bekkestua in the Bærum municipality of Norway. The cable is an air-cable, mounted on poles. The transmission system is utilising a single fibre for both, transmission and reception, connecting the terminal at the subscriber side through a 1 Gbit/s Ethernet link to a switch at the central office side. At the subscriber side, the received signal is split using a passive optical 50/50 splitter, feeding a first part of the signal to the subscriber terminal and the second part of the signal to the SoP monitoring node input. The data recorded by the SoP nodes is then uploaded to the SoP collector through a Wi-Fi connection from the SoP monitoring node to the home-terminal.

On August 15, 2022 between 17:50 and 18:20 CET a thunderstorm hit the area of the monitored cable causing heavy wind and rain as well as lightning and thunder. The weather conditions where observed at the location of the subscriber and were later confirmed with data from weather stations. A weather station at Tryvann, in approximately 8 km distance from the cable, shows observed wind-gusts of up to 20 m/s at peak during the period of the thunderstorm. The wind caused the air-cable to sway heavily during the wind-gusts. The fluctuations of the monitored relative SoP variations was calculated during 30 minutes with a 1 minute window size and a moving average method, using the absolute values of the relative SoP variations. Fig. 3 presents the moving average of the SoP variations induced by the thunderstorm. The observed trends show an increase at 17:57, followed by a decrease and then an increase in the intervals [18:05, 18:08] and [18:14, 18:20]. Using the moving average indicates when the intensity of the wind and rain is peaking and its power. In Fig. 4, the relative SoP variations are plotted as a function of time, illustrating rapid fluctuations strongly increasing and decreasing in amplitude, following the weather conditions.

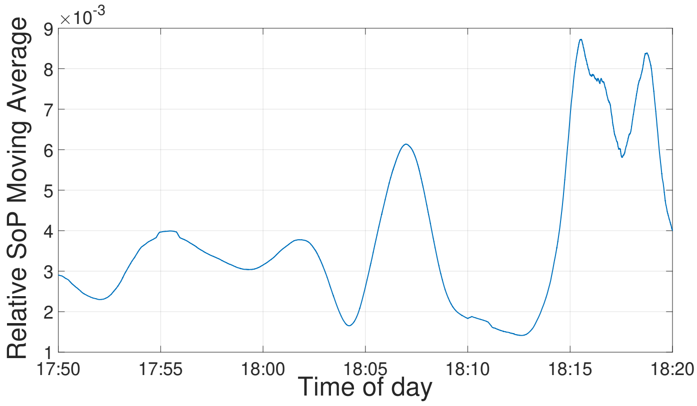

Fig. 3. The relative SoP moving average with 1 minute time window, from 17:50 CET to 18:20 CET on 15-Aug-2022.

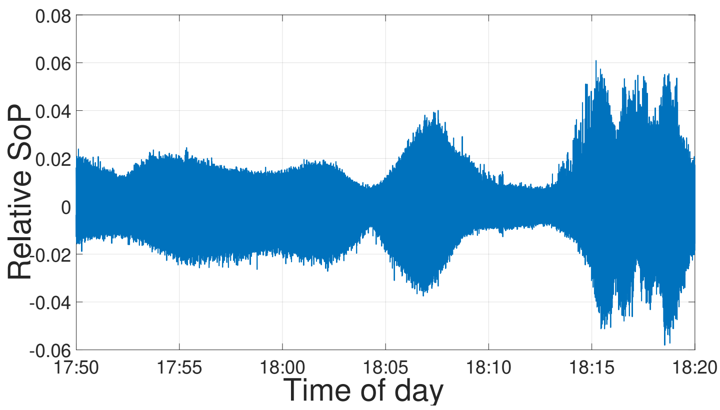

Fig. 4. The relative SoP in time domain, from 17:50 CET to 18:20 CET on 15-Aug-2022.

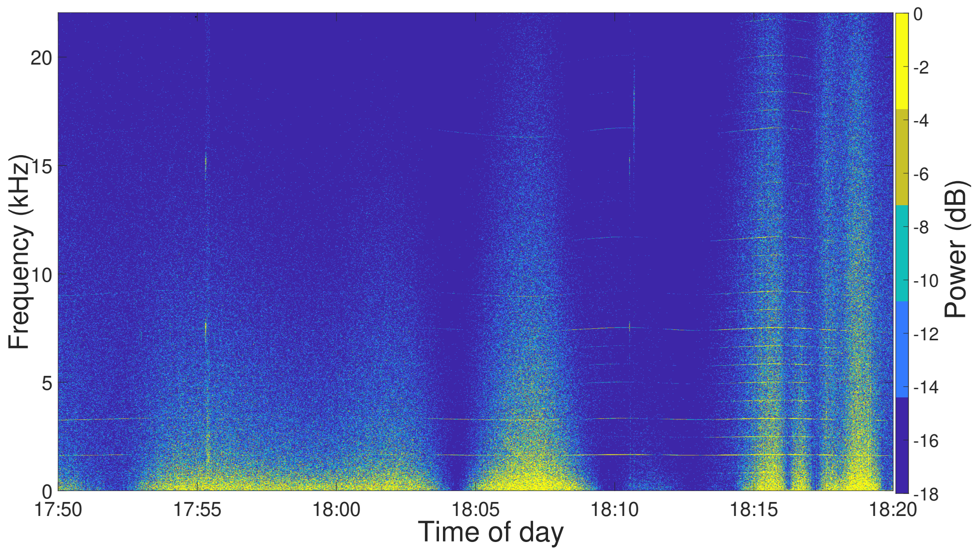

Fig. 5. The relative SoP in time-frequency domain, from 17:50 CET to 18:20 CET on 15-Aug-2022.

For a deeper analysis of the signal, the frequency content is plotted as a function of time, with the colour indicating the power of the signal. Fig. 5 shows that during moderate fluctuations, the signal content is distributed with frequency components up to approximately 1 kHz, while during the strongest peaks, frequency components gradually decrease in amplitude up to the upper cut-off frequency of 20 kHz. For the strongest peaks, also discrete frequency components are observed. We assume that this may be caused by resonances in the steel-wires attaching the fibre-cable spans to the poles. At around 17:55 and 18:11, narrow vertical lines occurs. Analysing the signal shows a bursty signal of approx. 1 s period. Further investigation will be performed finding the source of this signal that the long-term observations shows also during quiet weather conditions. Weather stations observed several lightnings within a 4 km radius of the cable during the thunderstorm and observation time of the plots. In our data, we have however not found patterns matching the time or form of lightning strokes. This may be due to e.g. the short length of the cable or the 20 kHz maximum monitoring frequency. From our observations, we conclude that the power of the impact from wind and rain on the air fibre-cables can be characterised using SoP monitoring. Furthermore, for these cables, SoP variations with frequency components beyond 20 kHz may be expected. Hence, similar to the needs in transport networks, future access network technologies that may use SoP as part of the modulation format will need efficient SoP compensation handling frequencies beyond 20 kHz, even in the absence of transient electromagnetic fields from lightning discharges.

4. Conclusions

Monitoring physical impacts on fibre-cables is of interest from both, a security and availability perspective, for limiting the risk of network outages by revealing unexpected or strong physical movements. We have proposed a scalable, low-cost monitoring infrastructure for the purpose of mass-deployment, adding sensing capability to the high-density fibre communication infrastructure. In this paper, we bring the first results from a 12 month duration ongoing field-trial monitoring SoP changes in a live 1 Gbit/s Ethernet signal in a FTTH air-cable attached to poles. During a thunderstorm, relatively strong SoP variations are observed due to heavy wind and rain, causing the cable to sway and vibrate. Plotting a moving average indicates how powerful the weather impacts the fibre-cable. Because cables in the access network are limited in length to a few kilometers or less, the monitoring gives local indications of weather conditions, even though spatial information is not present in the monitored signal. The frequency content of the signal shows a wide-band signal with frequency components from below 20 Hz and beyond 20 kHz, indicating that efficient compensation will be needed for any future access network system using SoP as part of the modulation format. Based on 12 months of collected data, further work will focus on identifying the different events causing the variety of patterns observed, as well as fingerprint identification of patterns caused by e.g. heavy weather and unexpected vibrations in the cable occurring from e.g. objects hitting the cable or the poles.

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