Abstract

The widespread deployment of optical fiber networks has drawn significant attention to a new research topic called "integrated sensing and communications" (ISAC), concerning the investigation of various solutions to enable sensing capabilities within telecommunication infrastructures. This thesis will address, in this context, the following main research questions and related contributions.

- **Integrating state of polarization (SOP) sensing into the optical telecommunication networks.** Coherent communication systems encode data on light's SOP, tracked at the receiver side. Since SOP is inherently sensitive to strain and temperature, sensing can be enabled without extra hardware, but with no event localization capability. We experimentally demonstrated SOP data retrieval from commercial transceivers, evaluated their estimation accuracy, and proposed algorithms to identify anomalous events. We proposed a non-adaptive and time-resolved algorithm, based on the SOP angular speed (SOPAS) computation, and a more sophisticated one, adaptive and frequency-resolved, called SOP-power spectral density gap (SOP-PSDG). The latter delivered enhanced detection capabilities in a metropolitan environment with respect to the SOPAS in all the cases tested.

- **SOP-based hazards detection in a mountain environment.** We investigated the use of SOP to monitor the mountain scenario, often subject to hazards (e.g., debris flow, rockfalls), through a standalone system (i.e., not connected to any telecommunication infrastructure) to deliver timely warnings. We studied the monitoring system on a reduced-scale model of a real mountain gully, and then scaled it up to a real environment. We demonstrated how the SOPAS-based detection algorithm can be reliable in this context, with lower costs compared to legacy geotechnical sensors.

- **Distributed acoustic sensing (DAS) and telecommunication systems coexistence.** The DAS technology is capable of precise strain/temperature measurements, and event localization along the fiber. We investigated intensity-modulated and direct-detected (IM-DD) data channels co-propagating with chirped-pulse DAS, a more advanced DAS technology. Our discoveries, confirmed by experiments and numerical simulations, found modulation instability (MI) to be the primary cause of crosstalk in telecommunication channels, which can be mitigated by increasing the frequency spacing between the sensing signal and the telecommunication channels, reducing the in-band DAS pulse noise level, or employing lower DAS pulse peak powers. For coherent telecommunication systems, we experimentally investigated a standard (non-chirped) DAS signal co-propagating with data combs in both the C- and L- bands. Our results indicate that C-band channels are affected by Kerr nonlinearities, primarily cross-phase modulation, also mitigated by increasing spectral separation. Moreover, we discovered that the Raman effect seems to compromise data integrity in the L-band. Telecommunication channels were never compromised if counterpropagated with the DAS pulse.

This thesis analyzes sensing techniques compatibility and coexistence with optical telecommunication systems, focusing specifically on state of polarization monitoring and distributed acoustic sensing. Rather than comparing these technologies to determine which is the better fit, this research provides a comprehensive characterization of both systems to facilitate their integration or addition into the existing infrastructure. By examining various deployment contexts, the study demonstrates how SOP and DAS can coexist, under different conditions, within the telecommunication infrastructure.