# SHORT TERM SCIENTIFIC MISSION (STSM) SCIENTIFIC REPORT

**This report is submitted for approval by the STSM applicant to the STSM coordinator**

**Action number: CA15127**
**STSM title:Resilience of Optical Networks to Natural Disasters (Working Group 1)**
**STSM start and end date: 17/11/2017 to 23/11/2017**
**Grantee name: Jacek Rak**

**PURPOSE OF THE STSM:**
(max. 200 words)

Communication capabilities of our society strongly depend on the global communication infrastructure primarily based on the fiber-optic equipment. However, consequences of failures in optical networks can be disastrous due to a large volume of traffic transported via optical links. A number of resilient routing techniques were originally proposed forscenarios of single failures of links (e.g., the accidental cable cuts by street works or damages of underwater cables by fishing vessels), as this scenario was considered to refer to about 70% of all failure cases in wide-area networks.

Currently, we observe a significant increase of frequency of natural disastersoccurrence leading tocorrelated failures of multiple network elements (e.g., due to earthquakes implying failures of underwater links or hurricanes responsible e.g., for power outages).

The purpose of this STSM was to:

(a) performanalysis of characteristics of multiple failures following from natural disasters in optical networks and assessment of their impact on the performance of the optical network infrastructure,
(b) discuss the design aspects of network architectures towards achieving/improving their resistance to disasters,
(c) prepare adraft table of contents of the chapter on*Resilience of optical networks to natural disasters*of the final CA15127-RECODIS book.

**DESCRIPTION OF WORK CARRIED OUT DURING THE STSM**
(max. 500 words)

This STSM was implemented at Norwegian University of Science and Technology (NTNU), Trondheim, Norway and was hosted by Prof. Poul E. Heegaard.

The issue of network resilience has been extensively studied in the literature over the last two decades in the context of unintentional actions primarily leading to failures of single network elements (mainly of optical links in the context of wide-area networks). Thework carried out during this STSM was related to resilience of optical networks under massive failures of optical network elements triggered by natural disasters.

The first taskrelated to the STSM purpose (a) above carried out during this STSM was to analyze characteristics of massive failures of optical network elements. A number of disaster events were

investigated, including the 2005 Hurricane Katrina, heavy rain falls as e.g., in 2004 in Zagreb, Croatia (causing a notable breakdown of the critical communication infrastructure), fires (in Greece or Spain, Italy in 2008, 2009), or earthquakes causing massive power outages and cuts of undersea optical links (as e.g., the 2011 Greatest Japan Earthquake, 2008 Shicuan Earthquake, or 2008 the Mediterranean Sea earthquake disrupting communications between Europe and Africa). Natural disaster events have been identified to be responsible for *region failures* denoting simultaneous correlated failures of neighboring physical elements of a communication network located in a certain geographic area, as their impact on network elements is commonly related with the geography of the network.

Concerning the assessment of impact of natural disasters on the performance of optical networks, the following measures/techniques were discussed: *k*-connectivity, Region Based Component Decomposition Number (RBCDN), Region-Based Smallest(Largest) Component Size, identification of geographical areas of a network that are the most vulnerable to disaster-based geographically correlated multiple failures (in the form of circular areas and line segment cuts).

In the context of the STSM purpose (b) above, several techniques of resilient routing were analyzed, e.g., the penalty model introducing the concept of a penalty (as a cost metric in path calculations) that should be paid to the customers for not fulfilling the SLA regulations aftera massive failure. Concerning the structure of a network in a post-disaster period, a scheme called movable and deployable units (MDRU) designed as containers with modularized equipment for information processing, networking and storage raised the attention as an efficient mechanism to restore communication capabilities in a disaster area.

The content of the chapter on *Disaster resilience of optical networks*of the Action final bookhas been also discussed, and a draft table of contents has been prepared.

These activities were accompanied by a seminar talk of the STSM Grantee on *Disaster-resilience of optical networks* on November 20, 2017.

**DESCRIPTION OF THE MAIN RESULTS OBTAINED**

The main results of this STSM include:

1. A document being a preliminary version of a publication describing:
   (a) characteristics of multiple failures following from natural disasters in optical networks,
   (b) the impact of disasters on the performance of the optical network infrastructure,
   (c) design aspects of network architectures towards achieving/improving their resistance to disasters,
2. A draft structure of a chapter on *Disaster-resilience of Optical Networks*of the Action final book
   (a) Impact of disaster events on optical networks
   (b) Characteristics of disaster-induced failures of optical network elements.
   (c) Methods to evaluate the vulnerability of optical networks to disasters
   (d) Schemes of disaster-resilient routing
   (e) Methods of design / evolution of architectures of optical networks to achieve their disaster-resistance
   (f) Summary

**FUTURE COLLABORATIONS (if applicable)**

STSM Applicant foresees further co-operation with the STSM Host in the area of *Resilience of optical networks to natural disasters* leading to preparation of a joint chapter of the Action final bookand apossible journal publication.