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Sifat Ferdousi

March 15, 2019

Introduction

- In case of large-scale disasters, optical networks can be fatally damaged or destroyed - including both data-plane (D-plane) and control-plane (C-plane).

- Standard proactive protection and restoration schemes (pre-disaster) may fail to protect/restore services in disaster area due to lack of surviving resources in D-plane and loss of the network control in C-plane.

- Quick and effective reactive post-disaster recovery of destroyed optical transport network infrastructure in the disaster area is essential.

- Especially, in the early phase of disaster recovery, it is highly desired to recreate partial optical networks first and satisfy the highest priority traffic as early as possible.

- Quickly collect the surviving and damage information of the network to efficiently plan disaster recovery.

Disaggregation and White-Box Approach

- In post-disaster recovery, conventional recovery approaches repair damaged network systems with same vendors' products progressively.
  - Disaggregation and white-box approach offer options for quick recovery with lower recovery costs.
    - Disregard vendor boundaries
    - Downsize the devices – easier to carry in unfavorable conditions
    - Disaggregation makes it easy to add/replace functions

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Emergency Optical System

- Develop prototype of a disaggregated portable emergency optical system (EOS) for early and low-cost post-disaster recovery.

- EOS is customizable, and different functions can be selected according to requirements during disaster recovery.

- In addition to optical node repairing in the D-plane (replacing damaged functions of original optical system), introduce two new disaggregated functions in the EOS:
  - An optical supervisory channel (OSC) handshake scheme and the corresponding OSC-handshake unit (OSC-HSU) in the EOS to facilitate interconnection of surviving multivendor optical resources in the D-plane.
    - These surviving multivendor optical resources can be interconnected to quickly construct an emergency optical network (EON) in the disaster area.
  - A C-plane network recovery scheme and the corresponding emergency C-plane unit (ECU) in the EOS to quickly recover the damaged C-plane network.
    - This scheme employs surviving or restored wireless access capability to reconnect broken C-plane network. Quick C-plane recovery is highly desired not only for emergency network control, but also for quick collection of network damage information.

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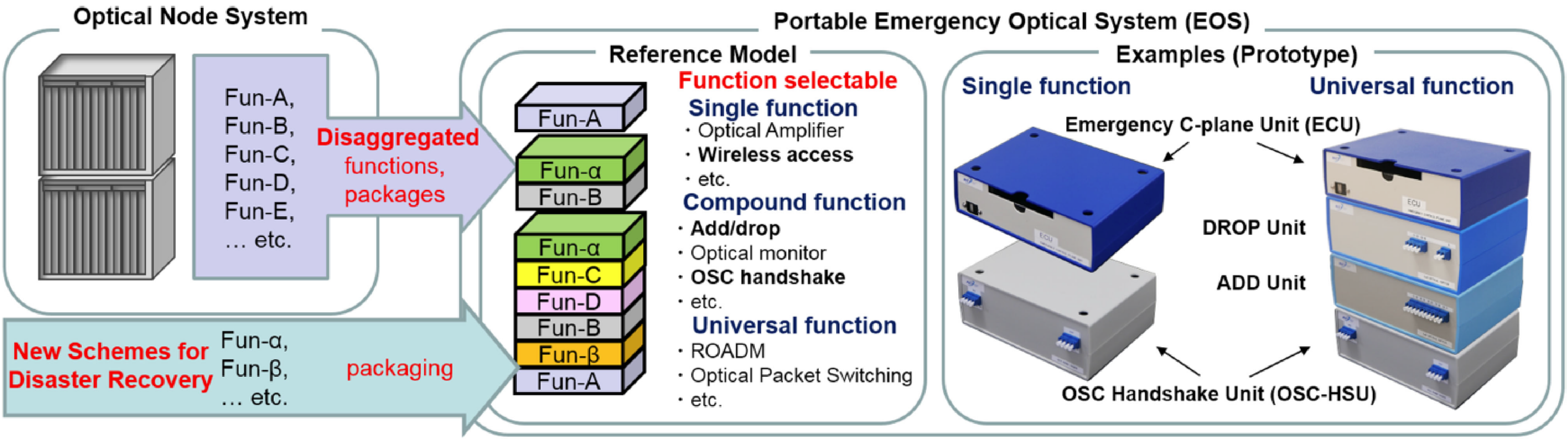
Concept of Portable EOS



Portable EOS

- Functions of original optical communication system integrated within one closed system are identified and disaggregated, e.g., Fun-A, Fun-B, etc.

- These disaggregated functions can be implemented and packaged within individual units and integrated into an EOS - can be customized to perform different functions.

- In post disaster recovery, according to degrees of damage, different functions (units) can be selected and implemented into different EOSs.
  - For heavy disasters, more functions in EOSs would be required.

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Portable EOS

- These EOSs will be carried by maintenance personnel and placed at the recovery sites. Each unit in an EOS is designed to be portable with a small size and light weight - can be carried on foot or by bicycle.

- Develop a prototype of the EOS, each portable unit of which is of width 245 mm, depth 175 mm, height 70 or 90 mm; in addition, these units can be stacked in a free order. The weight of each unit is less than 1 kg.

- EOSs are new resources to be interconnected with existing surviving optical resources (multivendor interconnection approach).

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Functions of Emergency Optical System

- *Conventional Functions:*
  - An optical node system such as a reconfigurable optical add/drop multiplexer (ROADM) consists of several functional components such as optical amplifiers, wavelength selective switches (WSS) for “ADD” and “DROP” functions, transponders, power monitors, optical supervisory channel (OSC), element management system (EMS), etc.
  - Functions in these components are identified and disaggregated - they are categorized as conventional functions, e.g., Fun-A, Fun-B, Fun-C, etc., which are employed to replace damaged portions of a ROADM in disaster recovery.

- *Advanced Functions:*
  - Besides aforementioned conventional functions, advanced functions are integrate in EOS, e.g., Fun-α and Fun-β, to facilitate quick recovery of both D-plane and C-plane.

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Conventional Functions

- Two types of conventional function units are developed (for first-stage study):

(1) WSS-based ADD/DROP units for recreating ADD/DROP functionalities,

(2) Emergency C-plane Unit (ECU) - a lightweight PC connected to C-plane network

- ECU is employed to implement various system control software packages, e.g., for control of ADD/DROP units.
- An emergency network controller can be implemented in ECU to perform emergency control of isolated portions of the network in disaster areas. Other new functions can also be implemented.

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Advanced Functions

- Two new advanced functions are introduced:

1) Aid of interconnection of surviving optical resources

- An OSC-handshake scheme and corresponding unit (i.e., OSC-HSU) to establish all-optical D-plane interconnections between surviving conventional ROADMs.
- Besides the OSC-related D-plane interconnection problem, for multivendor ROADM control, implement a multivendor ROADM configuration-command translation middleware in the ECU*.

2) Quick recovery of C-plane network via surviving/restored wireless access

- In ECU, a novel function that enables automated C-plane recovery with 4G mobile networks and Internet access capabilities.

S. Xu *et al.*, "Multi-vendor interconnection-based emergency multi-layer networks in disaster recovery," in *Proc. Design Reliable Commun. Net.*, pp. 179–184, Kansas City, MO, USA, Mar. 2015.

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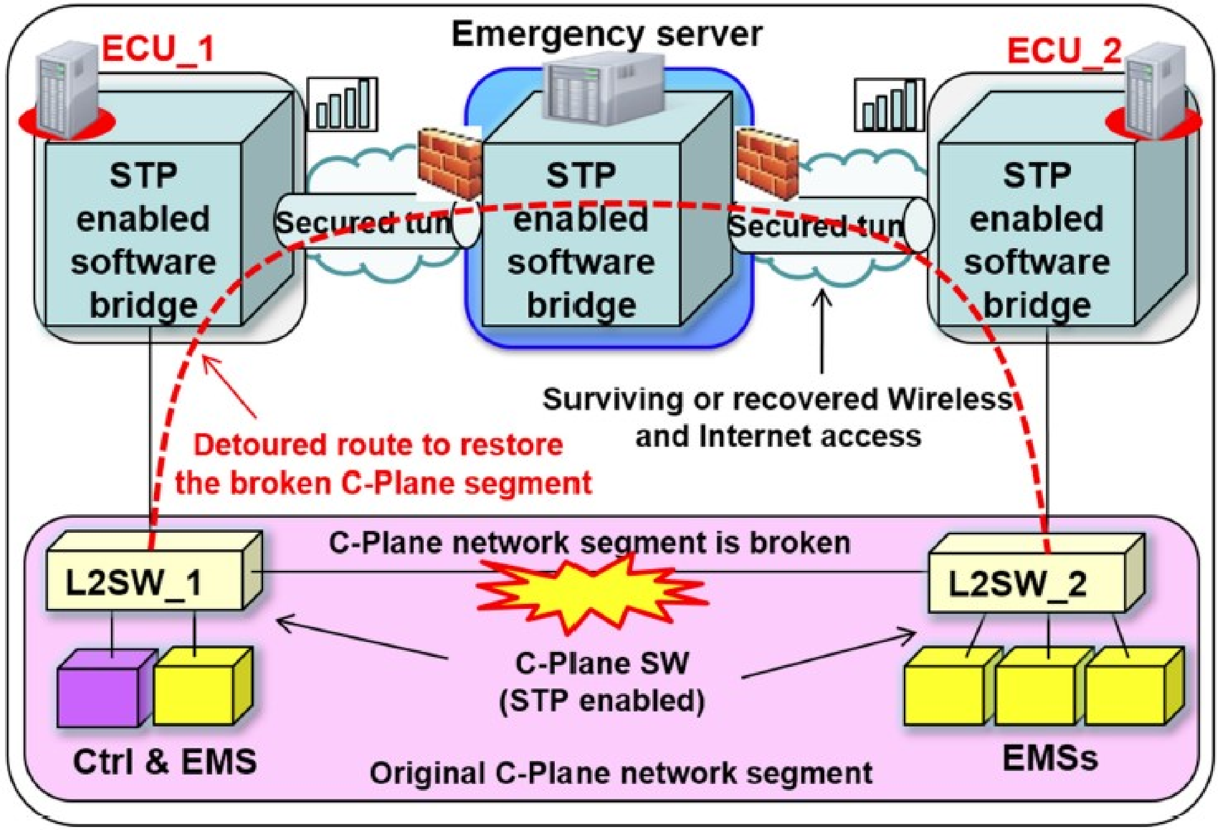
Emergency C-Plane Unit (ECU)

- Figure shows Ethernet-based C-plane network segment damaged during a disaster. In each C-plane segment, it is assumed that spanning tree protocol (STP) is enabled. Due to C-plane network failures, nodes in the C-plane segment (e.g., orchestrator, network controller, and EMS) are divided into isolated sub-segments. To recover them quickly, employ multiple ECUs (e.g., ECU_1 and ECU_2) in disaster area and a PC-based emergency server (ES) outside disaster area. An ECU is implemented with a lightweight portable PC equipped with two network interface cards (NICs).
- One NIC is connected to the original C-plane segment and it is called as C-plane NIC herein. Another NIC is connected to a built-in or attached wireless terminal system (e.g., 4G mobile terminal or satellite link system). ES outside the disaster area is connected to Internet. An STP-enabled software bridge system is implemented in each of the ECUs and the ES.
- By accessing surviving wireless network that is connected to Internet, each ECU can create a secured layer-2 tunnel (e.g., over the secured shell (SSH) service) between ES and itself. On ECU side, this secured tunnel is bridged with the C-plane NIC. On ES side, all secured tunnels from ECUs at different places are bridged together.
- With aid of multiple ECUs and the ES, a collection of detoured routes can be created to reconnect the isolated C-plane sub-segments. Note that for recovery of different C-plane segments, different Ess can be employed, one for each C-plane segment, respectively.



Detoured route construction with surviving or early restored wireless and Internet access.

- *Quick Restoration of C-plane Network via Surviving/Restored Wireless Access*
  - *Phase I: C-plane reconnection with emergency wireless connections*
  - *Phase II: Repair of the original damaged C-plane*
  - *Phase III: Automated maintenance of emergency wireless connections*

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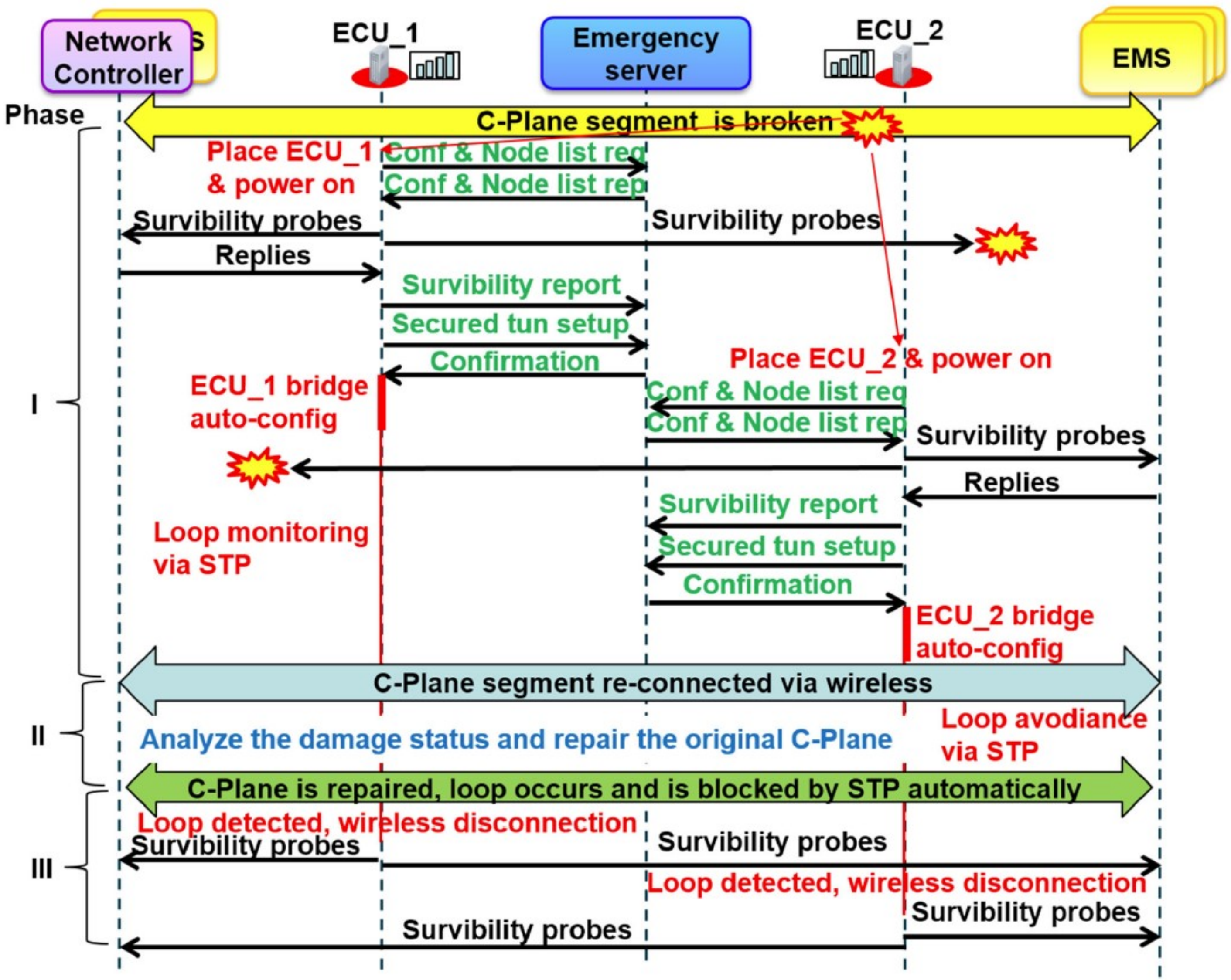

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