Conclusions
Multi Layer Resilience
Single Layer Resilience
Network Scenarios
Introduction

Outline

Recovery in Multilayer Networks

E4+ Summer School Zagreb

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The impact of network failures

5 billion lost calls

1 call, 700,000 bytes, 1.5 sec

The impact of lost packets

Increase in the demand for high-speed internet access in Japan

Conclusions

Multi-Layer Resiliency

Optical Transmission Network (OTN)

Multi-Protocol Label Switching (MPLS)

Internet Protocol (IP)

Network Scenarios

Introduction

Outline

Actions

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<td>Internet Bounces</td>
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<td>Messages Redirection</td>
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<td>Messages Returned</td>
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<td>Messages to Hosts</td>
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<td>Number of Failures</td>
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</table>

Some Failure Rates

Network Connectivity

Map of European Networks

Some failure rates for an optical cable network.
Conclusions
Multi Layer Resilience
Single Layer Resilience
- Optical Transmission Network (OTN)
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Network Scenarios

Introduction

Outline

How to fill the routing tables?

Future

Today

Network Scenarios
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Network Scenarios

Outline

MPLS Forwarding

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RSEP-TE

Label Distribution

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...Labels may be determined by IP routing. TE
destination address
- Forwarding based on labels in stead of IP
to preclude, for example, protection path
- Routes should not follow the shortest path
- engineer's protection strategy
- Set-up routes in the network for traffic

MPLS: Why and How?
To Remember

- Wavelength (label) on each link
- Specific path with fixed high BW

: OTN

: Should not be shortest route
: MPLS label on each link
: MPLS: packets follow shortest route
: IP destination address
: Routing table based
: IP

Core Transmission Networks

Mesh more flexible

1000 nodes \(= \frac{0.5}{N} \) million links
Full Mesh of N-Core Nodes

Transmission Links

InTEC
Difficult to speed up
- (10s)
- This can take up a lot of time
- Updating the new routing tables
- Recalculation of shortest paths
- Advertisement of new link-state packets
- Detection of failing link

The different phases:

Restoration In IP

What happens at the higher layer?

Restoration In IP

Light Layer Resilience
- Optical Transmission Network (OTN)
- Multi Protocol Label Switching (MPLS)
- Internet Protocol (IP)

Single Layer Resilience

Outline
Multi Layer Resilience
Optical Transmission Network (OTN)
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Routing

MPLS Recovery: An Overview

Facility Backup: Example

Local Protection (or Fast-Reroute)
**Conclusions**

- Case study
- Multi-layer Survivability architecture
- Recovery Interworking techniques

**Multi-Layer Resilience**

**Single Layer Resilience**

**Network Scenarios**

**Introduction**

**To Remember**

- Small number of paths
t- Also more difficult / multiple solutions
  - OTN
  - Possibility very large number of paths
- Much faster
- More difficult / multiple solutions
  - MPLS
  - But slow
- Very easy / one solution
- IP
Secondary failures

Single Layer Recovery

- Optical protection
  - Large granularity → few recovery actions
  - Close to root failure
    - No delay due to failure propagation
    - No need to deal with complex secondary failures
  - Known to be fast (at least protection)
  - BUT: cannot recover from all failures
- IP-MPLS recovery
  - For sure, better failure coverage
  - MPLS protection (making use of pre-established backup LSPs) can also be fast
  - BUT:
    - Can be confronted with complex secondary failure scenarios
    - Fine granularity → many recovery actions
    - During recovery increased usage of capacity → decreased QoS

- Conclusion: combine recovery at both layers

Outline

Introduction
Network Scenarios
Single Layer Resilience
Multi Layer Resilience
  - Single Layer Recovery
  - Recovery Interworking techniques
    - Uncoordinated
    - Hold-off timer
    - Summary
  - Multilayer survivability strategies
  - Case study
Conclusions

Without coordination
Conclusions

Multi Layer Resilience

Single Layer Resilience

Network Scenarios

Introduction

Outline
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**Faculty of Electrical Engineering and Computing, University of Zagreb, September 4-6, 2006**

**Optical Grid and Optical Network Resilience**

*e-Photon/ONE+ Summer School 2006*
September 4-6, 2006
Zagreb, Croatia

and Computing
Faculty of Electrical Engineering
University of Zagreb

Optical Grid and Optical Network Resilience

e-Photon One