Path Based *p*-Cycle for Resilient MPLS Network Design

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To my husband

Zheng Liu

Abstract

Resilient networks are those that are capable of continuously offering telecommunication services in the presence of network failures. New paradigms for reliable network design have been emerging and constantly improving network survivability. Failure-Independent Path-Protecting (FIPP) *p*-cycles are a path based extension of the well-known *p*-cycles and inherit the attractive properties of ring-like recovery speed and mesh-like capacity efficiency. They are suitable for application to the MultiProtocol Label Switching (MPLS) protocol that is widely used in Next Generation Networks (NGNs), in that it provides shared, failure independent, end-to-end protection to whole working paths.

This thesis contributes to advance in the state of the art for FIPP *p*-cycle based resilient networking. We firstly examine the two basic models: known as FIPP-SCP and FIPP-DRS. This is followed by an introduction to a Joint Capacity Allocation (JCA) design based on the FIPP-SCP model, which is more favourable to be used in MPLS networks.

The network design is referred to as the MFIPP-JCA model and involves three specific cases:

i) The BR model allows for bifurcated normal routing and imposes no restriction on the use of FIPP *p*-cycles;

ii) NBR or non-bifurcated routing, focuses on single path routing, while it retains the flexibility of a protection domain;

iii) An SNBR model where the main difference from the NBR model is that only a single FIPP *p*-cycle can be used to protect a working path.

Case studies investigated the performance of the MFIPP-JCA models and, for a comparison with the basic FIPP-SCP model. The main areas of interest include the total

cost of capacity, the number of FIPP *p*-cycles, and the solution time. The studies are also performed regarding changes in performance with regard to the number of eligible cycles. Those candidate cycles are the N-shortest cycles that are selected on either a circumference-based or hop-based criterion. The final contribution of this thesis is an in-depth discussion on the implementation issues for FIPP *p*-cycles in MPLS networks. We propose two operation modes both for bidirectional FIPP *p*-cycles, and make a judgment on the potential of unidirectional FIPP *p*-cycles.

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AMPL	A Mathematical Programming Language
ATM	Asynchronous Transfer Mode
B&B	Branch and Bound
BR	Bifurcated (Normal) Routing
BIP	Binary Integer Programming
CAC	Call Admission Control
CSPF	Constrained Shortest Path First
DRS	Disjoint Route Set, or specific to the FIPP-DRS method
FEC	Forwarding Equivalency Class
FIPP	Failure-Independent Path-Protection
FIS	Fault Indication Signal
FRR	Fast Reroute
FTN	FEC-to-NHLFE Map
ILM	Incoming Label Map
ILP	Integer Linear Programming
IP	Internet Protocol
IS-IS	Intermediate System to Intermediate System
JCA	Joint Capacity Allocation
LDP	Label Distribution Protocol
LER	Label Edge Router
LIB	Label Information Base
LP	Linear Programming or Linear Program
LSP	Label Switched Path
LSR	Label Switched Router
MCMF	Multi-Commodity Maximum-Flow

MIP	Mixed Integer Programming
MPLS	Multi-Protocol Label Switching
NBR	Non-Bifurcated (Normal) Routing
NEPC	Node-Encircling *p*-Cycles
NHLFE	Next Hop Label Forwarding Entry
O-D	Origin-Destination
OSPF	Open Shortest Path First
PDH	Plesiochronous Digital Hierarchy
PHP	Penultimate Hop Popping
PLR	Point of Local Repair
PML	Path Merge LSR
PSL	Path Switch LSR
QoS	Quality of Service
RHS	Right Hand Side
RSVP-TE	Resource Reservation Protocol – Traffic Engineering
SCA	Spare Capacity Allocation
SCP	specific to the FIPP-SCP method
SDH	Synchronous Digital Hierarchy
SNBR	Non-Bifurcated Normal Routing with Single Backup Structure
SONET	Synchronous Optical Network
VPLS	Virtual Private LAN Service
VPN	Virtual Private Network
WDM	Wavelength Division Multiplexing