A Multi-Path Load-Shared Failure Recovery Scheme Based on Network Coding

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Contents

Introduction

- Five dimensions of convergence
  - Business convergence
  - Terminal convergence
  - Service convergence
  - Management convergence
  - Network convergence
- To fulfill the needs of NG multimedia APs, Managed IP network should be
  - QoS capable
  - Embedded with failure recovery and secure transmission

Related Works

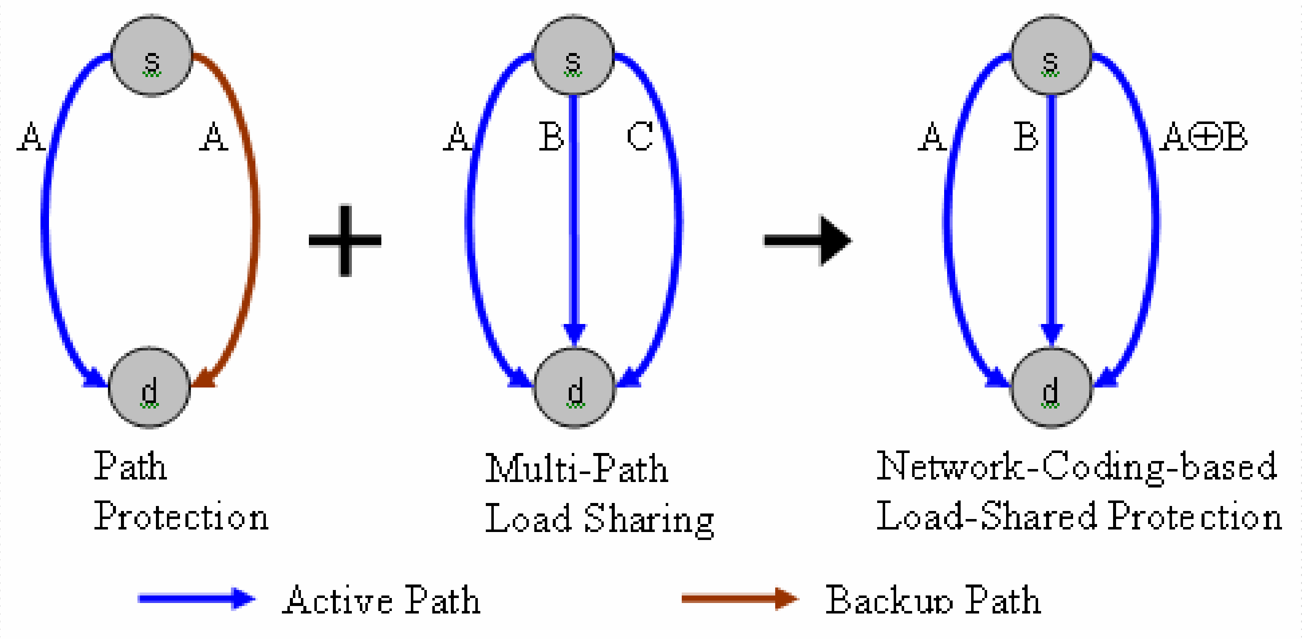
- Failure Recovery

	Protection	Restoration
Path	faster switchover bandwidth efficient	slowest switchover more bandwidth efficient
Link	fastest switchover more bandwidth inefficient	slower switchover bandwidth inefficient

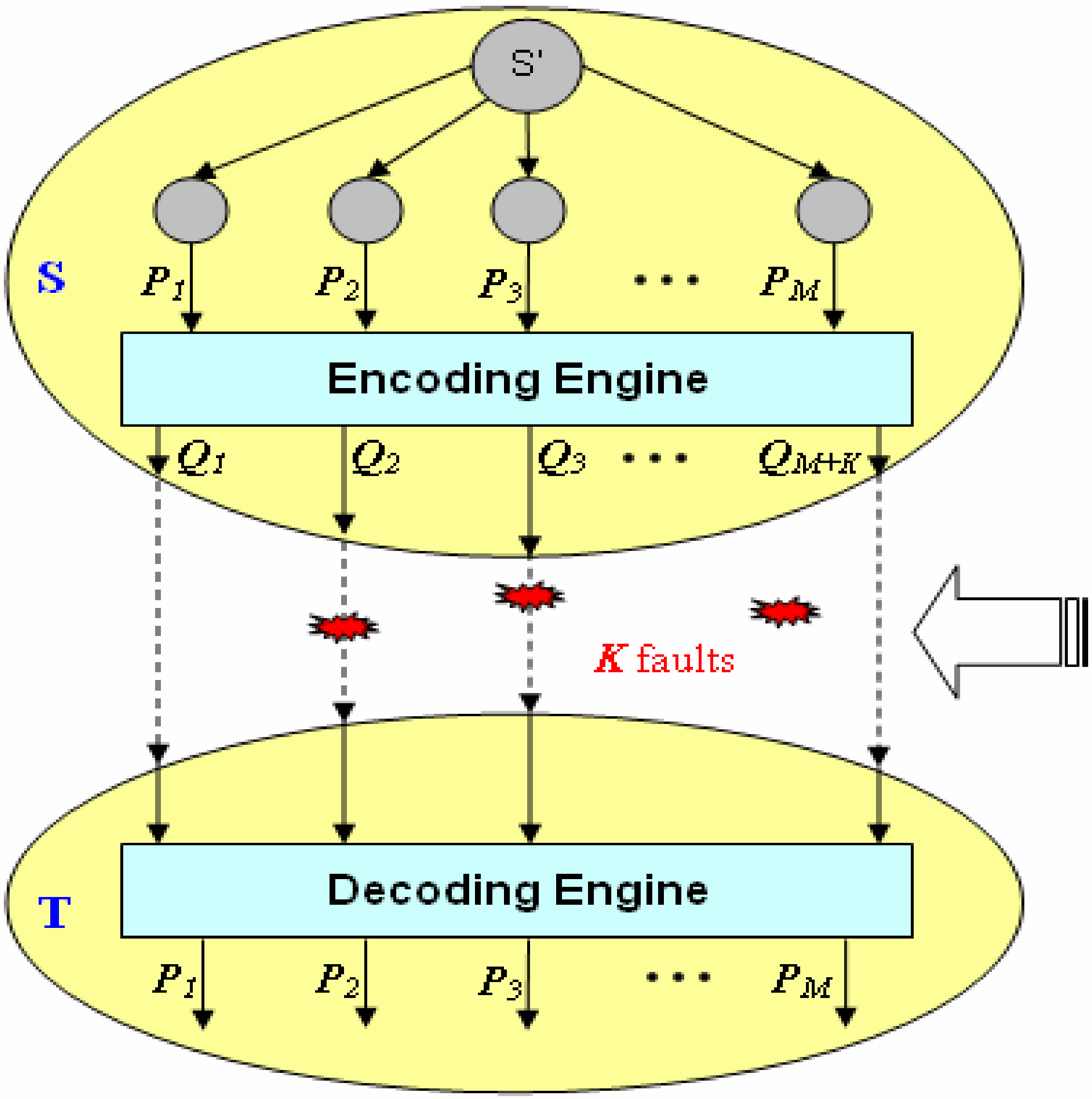
- Network Coding
  - Network coding was first introduced to solve the problem of network information flow
  - Various applications of network coding including P2P, wireless network, Ad-hoc sensor network, network monitoring and network security
  - New application of network coding on failure recovery

Design Idea of NC-LSP

- To benefit from
  - High availability of path protection
  - High bandwidth efficiency of multi-path load sharing



$M+K$ NC-LSP



Examples:

Generate packets Q_i's at node **S** by linearly combining P_1, P_2,....., P_M

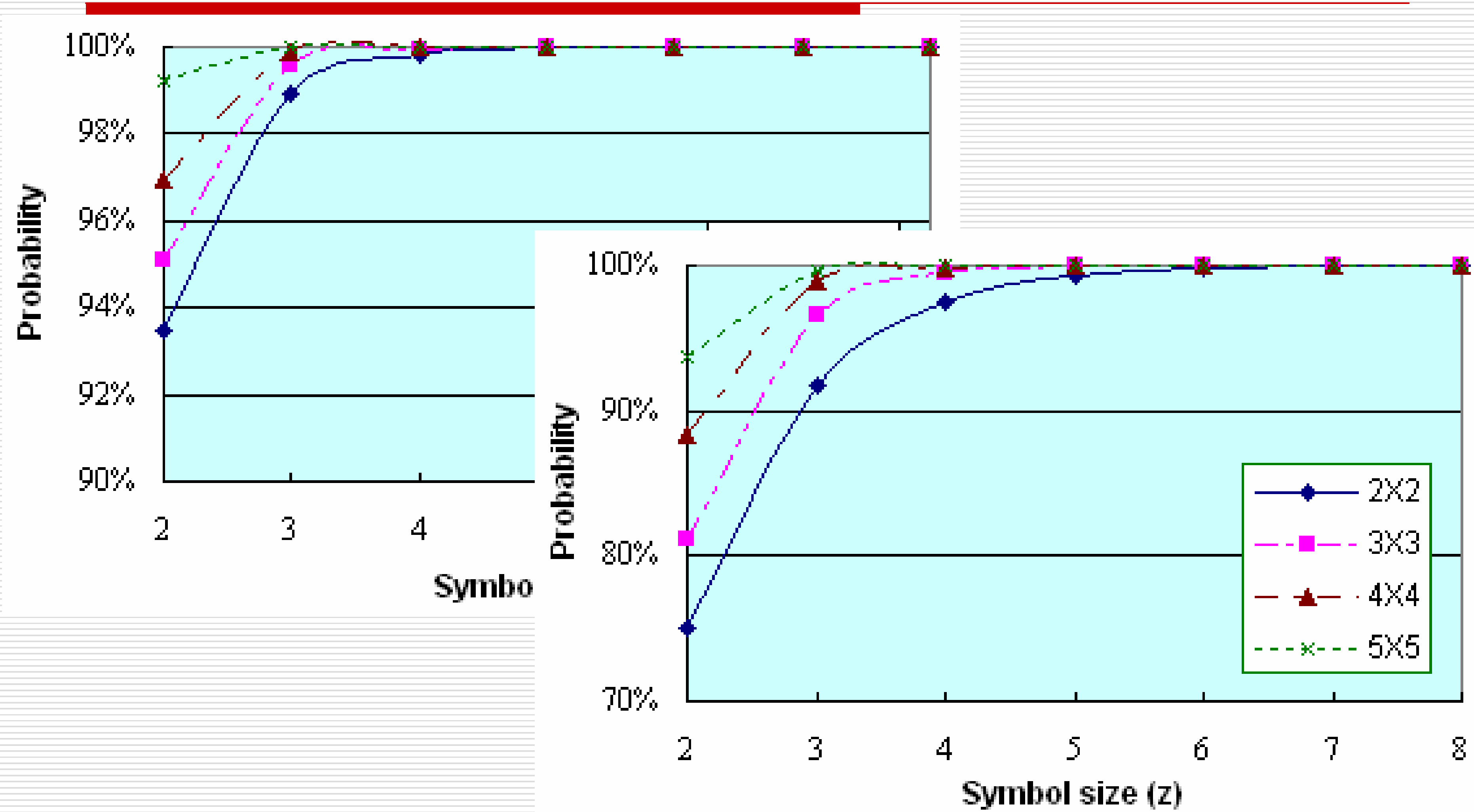
$M+K$ disjoint paths from node **S** to node **T** thus allowing at least K faults simultaneously

Receive at least M packets Q_i's at node **T** by solving M linear equations

$M+K$ NC-LSP

- Q1: What is a feasible encoding scheme?
  - Linear network coding is selected because of its polynomial time complexity
- Q2: What is the successful decoding ratio if using random linear network coding?
  - Approaching 100% if the symbol size used for coding/decoding is reasonably large
- Q3: what is the total service downtime that can achieve?
  - No switchover required for NC-LSP
  - There will be no service down if no more than K faults occur simultaneously

Successful Decoding Ratio



Detailed Algorithm

Step 1: Find $M+K$ disjoint paths from ***s*** to ***t*** .

Step 2: On source node ***s***,

2a Divide the demanding bandwidth B into M equal parts, each part with bandwidth B/M

2b Whenever transmission, encode M packets into $M+K$ coded packets using random linear network coding as follows

(1) For each path (the ith one) among the $M+K$ paths, select M random coefficients of GF(2^z), that is, c_{i1}, c_{i2}, ..., c_{iM} .

(2) Generate the ith coded packet $\boldsymbol{Q}_i = c_{i1}\times\boldsymbol{P}_1 + c_{i2}\times\boldsymbol{P}_2 + \ldots + c_{iM}\times\boldsymbol{P}_M$.

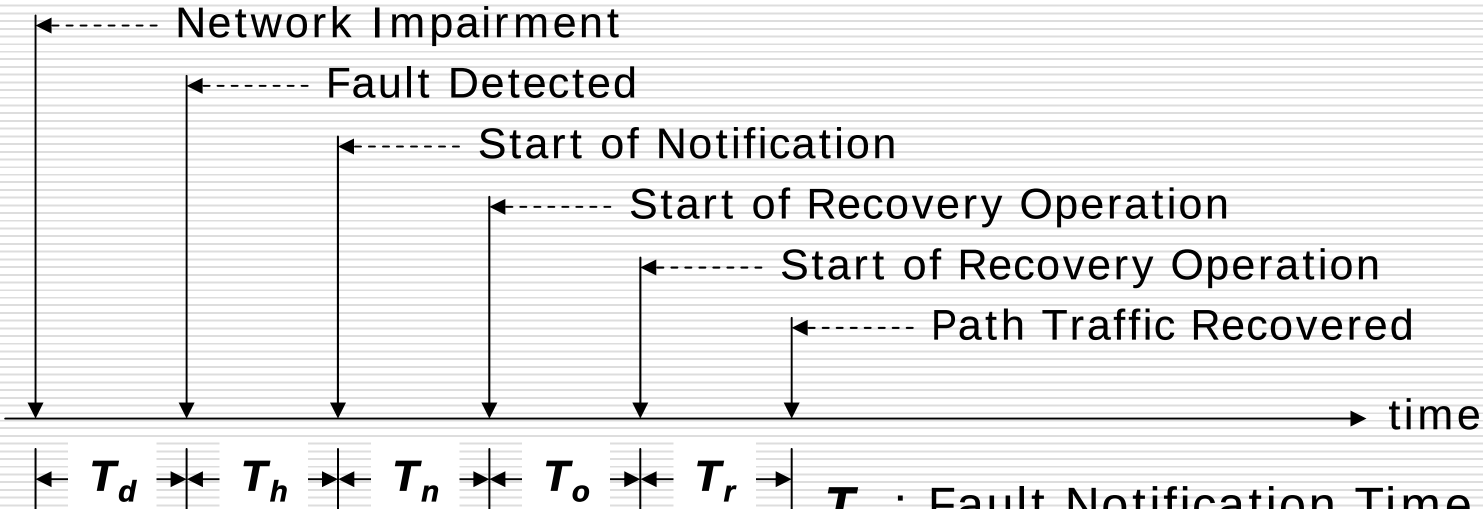
2c Send the $M+K$ coded packets over the corresponding $M+K$ paths.

Step 3: On destination node ***t***,

Recover M original packets by solving the set of M linear equations if receiving M or more coded packets

Downtime Analysis (1/2)

- Based on recovery model in RFC 3469
  - Re-routing
  - Protection switching



T_d : Fault Detection Time
T_h : Fault Hold-off Time
T_n : Fault Notification Time
T_o : Recovery Operation Time
T_r : Traffic Recovery Time

Downtime Analysis (2/2)

- Service downtime for protection switching
  - Time to switchover from active path to backup path
  - Multiple faults occur simultaneously on both active and backup paths
  - $SDT = (T_d+T_h+T_n+T_o+T_r)*N_{so}(T)+(1-p_a)*(1-p_b)*T$
    $N_{so}(T)$: the number of switchover during the period T;
    p_a, p_b : path availability for active and backup paths
- Service downtime for $M+K$ NC-LSP
  - No switchover required, service availability is

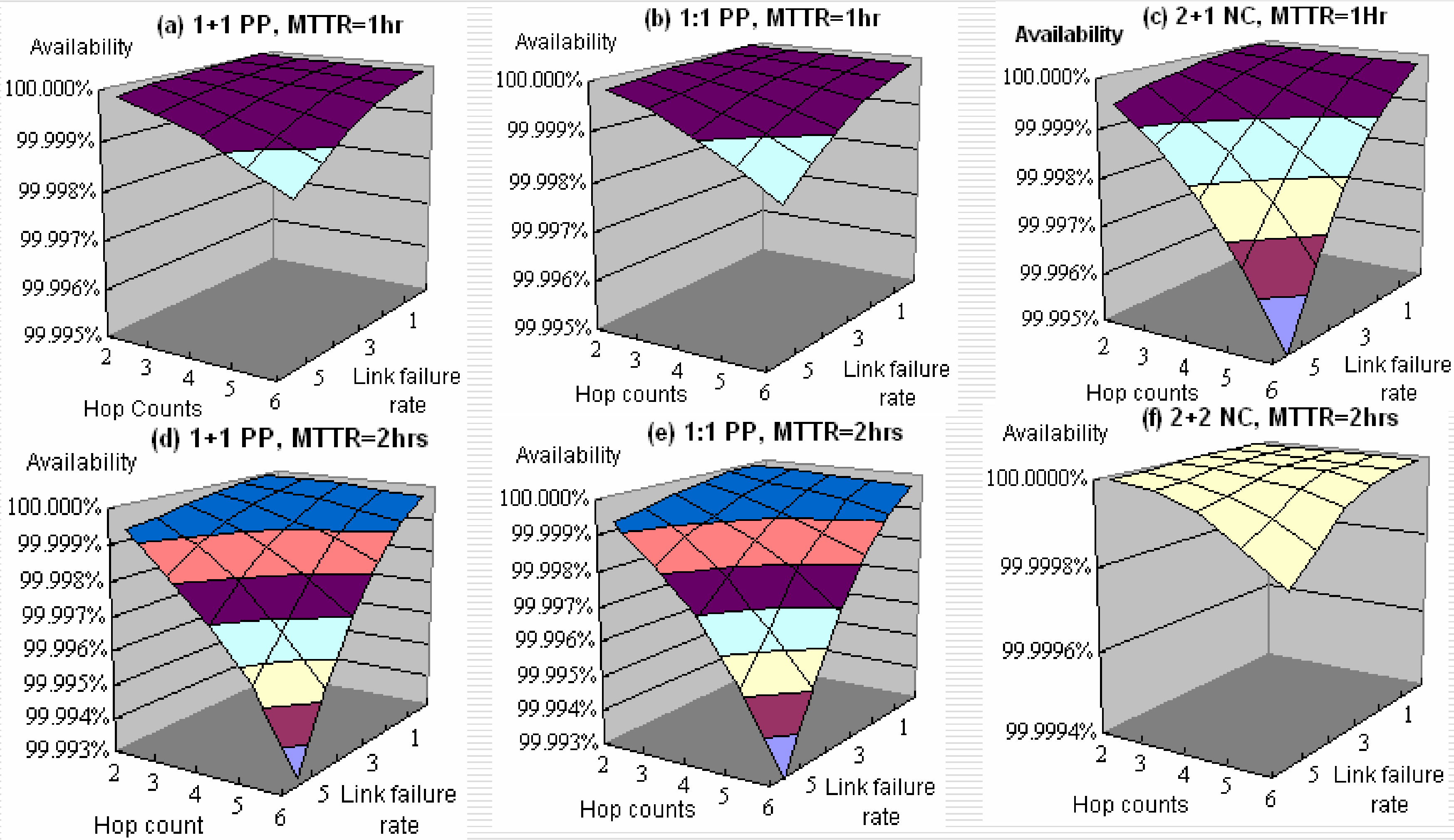
$$SA(M,K) = \sum_{x=0}^{K} \binom{M+K}{x} \times p^{M+K-x}(1-p)^x$$

  - Path availability $p= (1/\lambda-\mu)/(1/\lambda)= 1-\lambda*\mu$
    λ=path failure rate, μ=mean time to repair (MTTR)

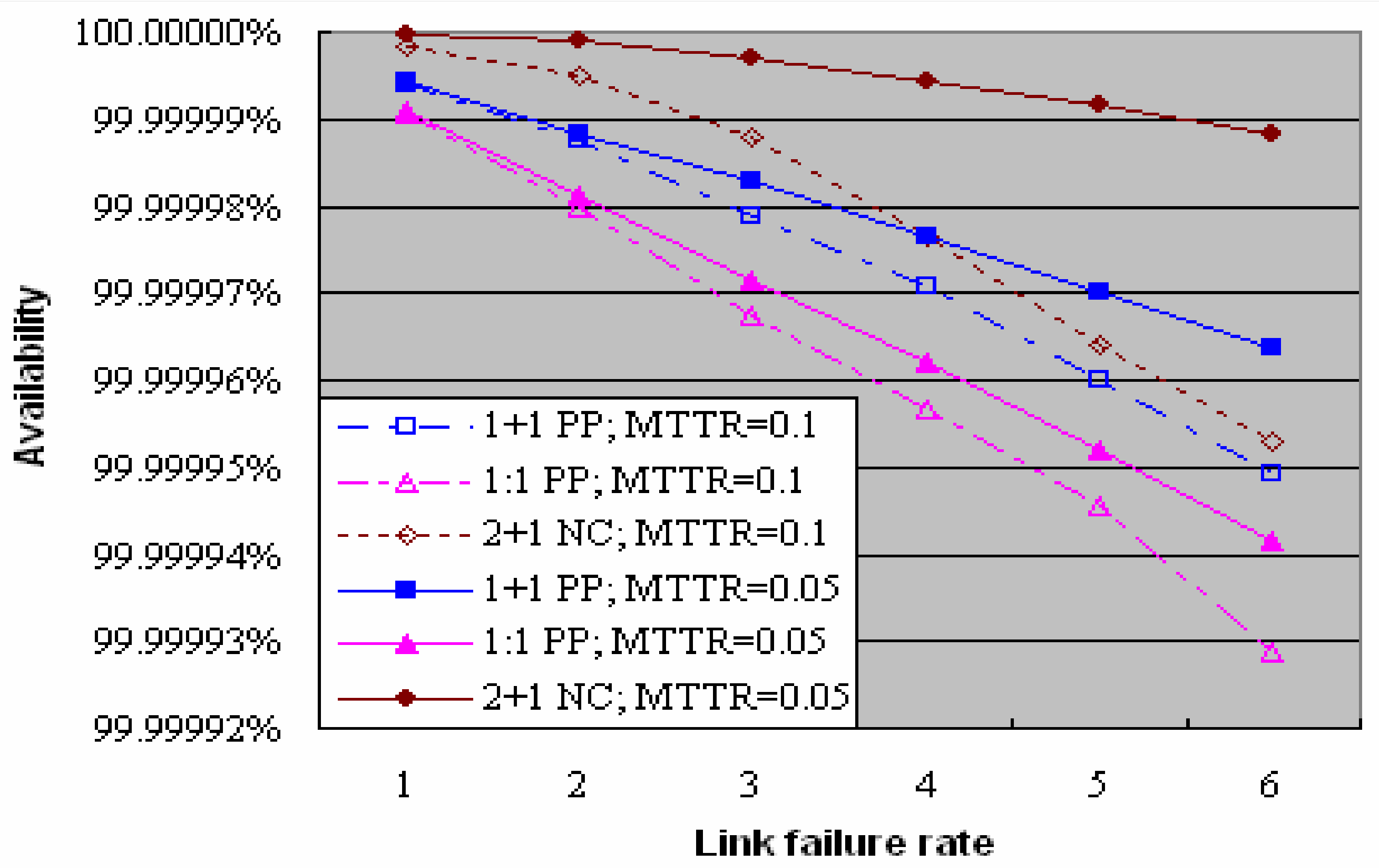
Simulation Experiments

- Single request
  - Evaluate the average service availability= (simulation time – service downtime)/simulation time
  - Assume multi-paths with equal hop count
- Multiple requests over a real network
  - Evaluate the average service down volume
  - Based on COST 239 network with 11 nodes and 25 bi-directional links
  - Capacity matrix in COST 239 is used as the traffic demands of each node-pair request

Service availability for single request

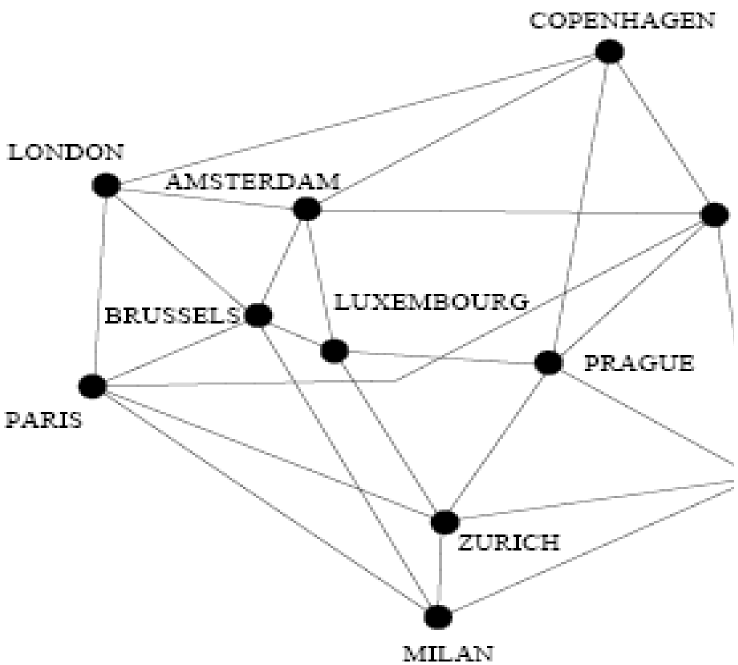


Service availability for single request of low MTTR



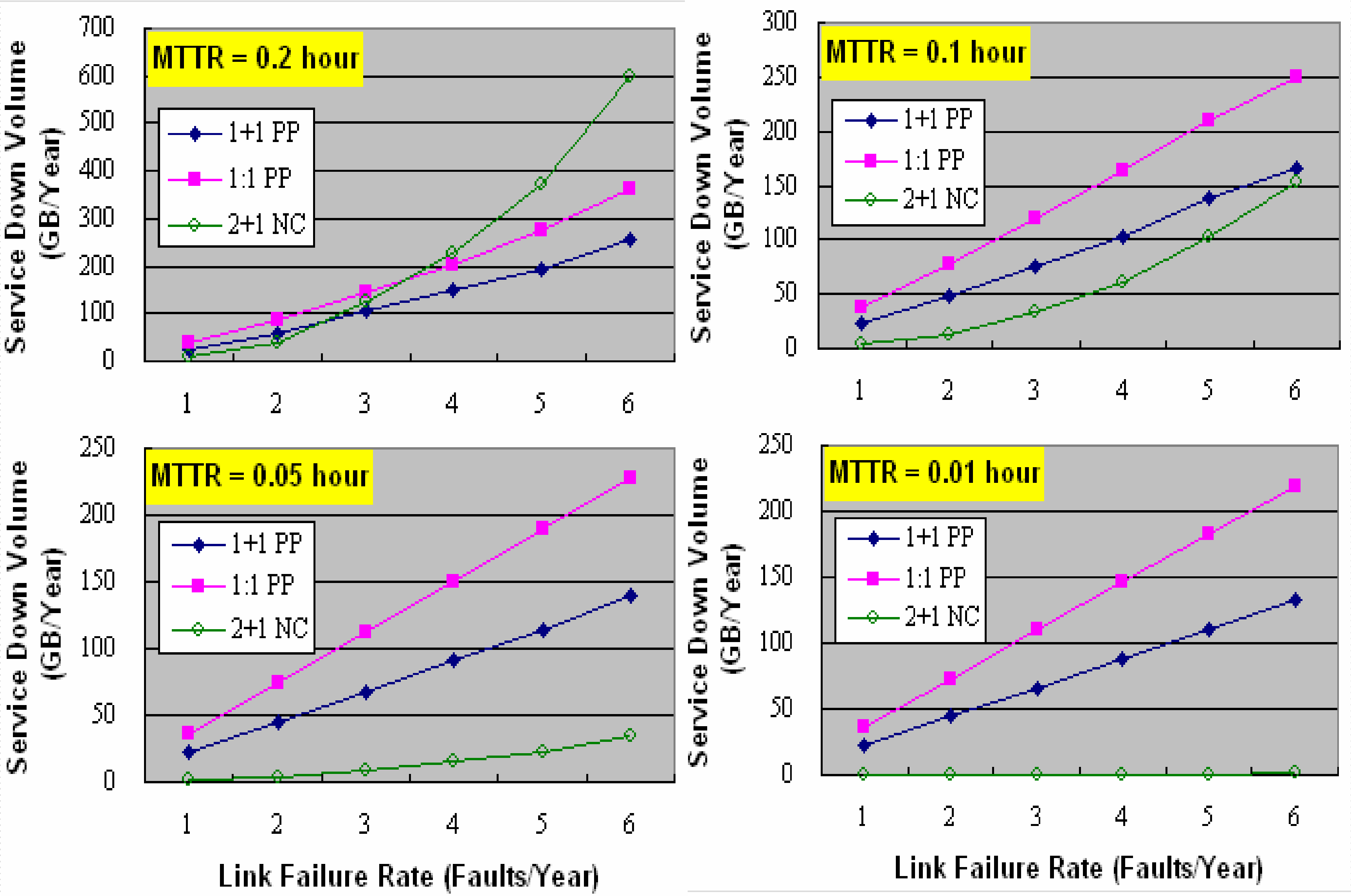
Simulation over COST 239

COST 239 network topology



Capacity Matrix												
Node	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	
0		10	2.5	10	10	10	2.5	2.5	2.5	2.5	2.5	Copenhagen
1	10		30	30	40	20	20	10	30	2.5	20	Berlin
2	2.5	30		10	10	10	10	2.5	10	2.5	2.5	Vienna
3	10	30	10		20	10	10	2.5	20	2.5	10	Milan
4	10	40	10	20		30	20	2.5	20	2.5	20	Paris
5	10	20	10	10	30		20	2.5	10	2.5	10	London
6	2.5	20	10	10	20	20		2.5	10	2.5	10	Amsterdam
7	2.5	10	2.5	2.5	2.5	2.5	2.5		2.5	2.5	2.5	Prague
8	2.5	30	10	20	20	10	10	2.5		2.5	10	Zurich
9	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5		2.5	Luxembourg
10	2.5	20	2.5	10	20	10	10	2.5	10	2.5		Brussels

Service down volume for multiple requests



Conclusions

- This paper proposed a novel failure recovery scheme by integrating path protection and multi-path load sharing.
- Under high failure rate and long repair time,
  - 2+1 NC-LSP is liable to experience service failure due to concurrent faults on multiple paths
  - 2+2 NC-LSP can achieve high availability
- Under reliable network and using IP re-routing to reduce network repair time,
  - 2+1 NC-LSP has advantage over the other recovery schemes to achieve nearly seamless failure recovery.

Discussion and Future Study

- The success of NC-LSP depends on
  - Existence of multiple disjoint paths
  - Short MTTR
  - Successful network decoding
- Future studies
  - Efficient algorithms to find multiple link/node-disjoint paths for source-destination pairs
  - Secure transmission paths based on linear network coding using pseudo-random stream