Survivability in WDM networks

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Some of the material is taken from the lecture slides of Prof. Biswanath Mukherjee, University of California, Davis, USA

Objective

- Concept of survivability in WDM networks
- Overview of the most common failures types:
  - link/fiber vs. node
  - single vs. multiple
- Fault management techniques
  - Protection vs. restoration

Network Survivability

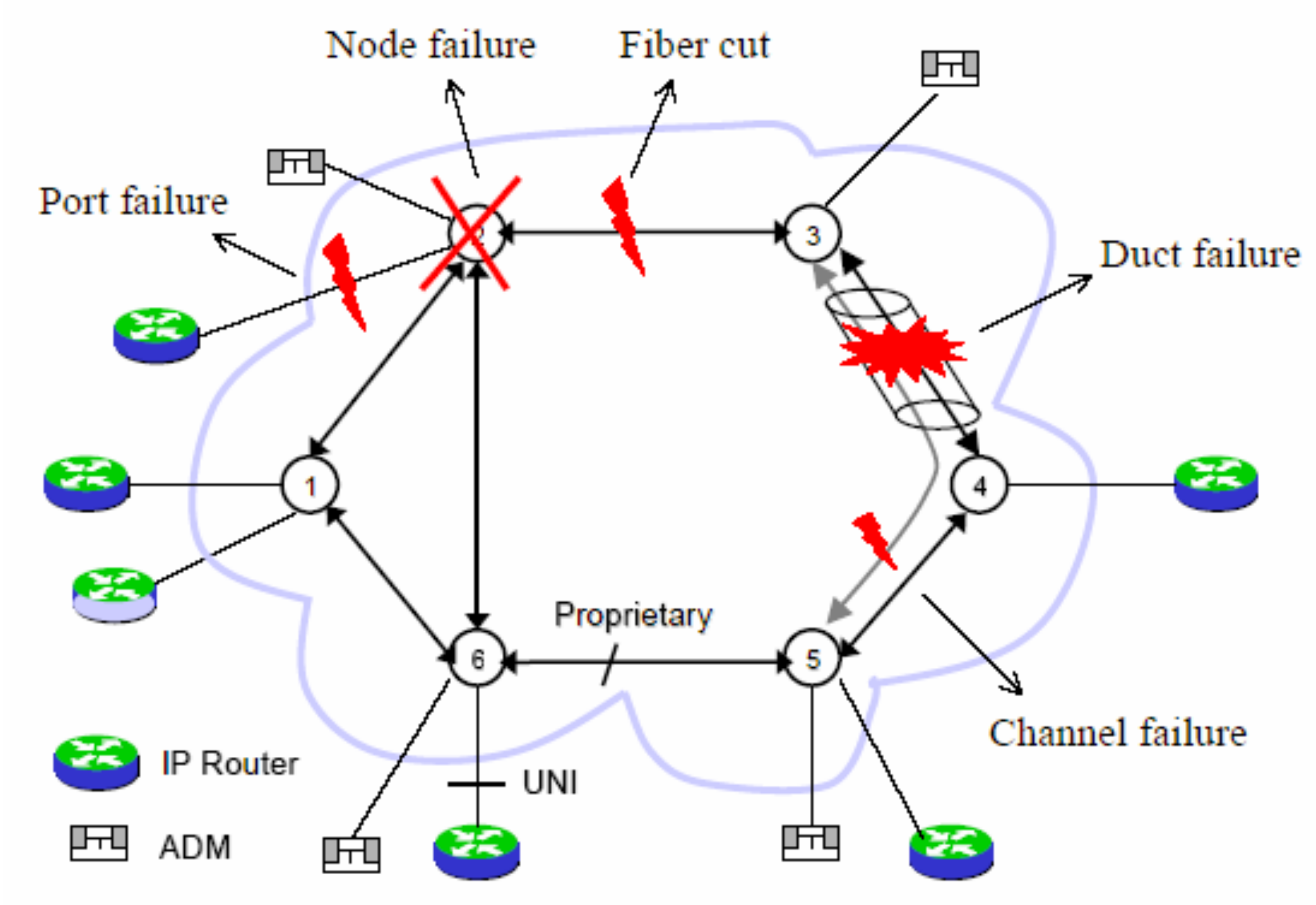
- Survivability: network's ability to continue to provide service in the presence of failures that may disrupt traffic
- A *duct* is a bidirectional physical pipe between two nodes
  - In practice, fibers are put into cables, which are buried into ducts under the ground
- A *fiber cut* usually occurs due to a *duct cut* during construction or destructive natural events, e.g., earthquakes
- All the lightpaths that traverse a failed fiber will be disrupted
- A fiber cut can lead to tremendous traffic loss

Failure types – fiber cut

- If a fiber supports:
  - 160 wavelength channels
  - each wavelength operating at 10 Gbps (OC-192)

  a fiber cut can lead to 1.6 Tbps data loss
- Fiber is laid in bundles (cables),
  - each cable carrying as many as 864 fiber strands,
  - each duct carrying many bundles (perhaps 10 or higher),
- a duct cut can lead to huge data loss

Which type of failures can we have?



Failure types – node and channel failures

- A central office (CO) can also fail where OXCs are located, because of catastrophic events such as fire or flooding. This is referred to as *node failure*
- Node failures are rare but the disruption will be very significant
- *A channel failure* is also possible in optical WDM networks
  - caused by the failure of transmitting and/or receiving equipment operating on that channel

Failure Rates

- The table shows some typical data on network component failure rates and failure-repair times, according to Bellcore (1994)
  - FIT (failure-in-time): the average number of failures in 10^9 hours
  - Tx: optical transmitters
  - Rx: optical receivers
  - MTTR: mean time to repair

Metric	Bellcore Statistics
Equipment MTTR	2 hrs
Cable-Cut MTTR	12 hrs
Cable-Cut Rate	4.39/yr/1000 sheath miles
Tx failure rate	10867 FIT
Rx failure rate	4311 FIT

Why survivability is important?

- With the high frequency of fiber cut and the tremendous traffic loss a failure may cause, *network survivability* becomes a critical concern in network *design* and its *real-time operation*
- Need to design effective methods to recover from failures of network links and nodes
- An individual *channel failure* can be handled locally by quickly switching to another idle local channel, or it can be handled as a link failure when no idle channel is available

Single vs. Multiple Failures

- Most of the research work on survivability in WDM networks focuses on the recovery from a single link or node failure
  - one failure is repaired before another failure is assumed to occur in the network
  - this is known as the assumption of *single failure scenario*
- Multiple (i.e., near-simultaneous) failures are also possible in a realistic network, and appropriate recovery methods can be designed

Shared Risk Groups

- Shared Risk Groups (SRG) express the risk relationship that associates all the optical channels with a single failure
- An SRG may consist of:
  - all optical channels in a single fiber
  - all optical channels through all the fibers wrapped in the same cable/duct
- Since a fiber may run through several conduits, an optical channel may belong to several SRG
- The provisioning algorithms must exploit SRG maps to discover SRG-diverse routes so that, after any conduit is cut, there is always at least one viable route remaining
- This constraint is the SRG constraint

Shared Risk Groups

- The SRG concept can be generalized to include a group of nodes and links that are in close proximity
- A large scale disaster covering a wide geographical region may disrupt all members of the SRG simultaneously
- Since link failure is the dominant failure scenario, shared-risk link group (SRLG) is a commonly-used form of SRG

Fault Management

- Survivability can be provided in many layers in the network
  - e.g., IP, ATM, SONET/SDH
- The fault-management schemes in each layer have their own functionalities and characteristics
- In an optical network, line terminals can detect the failures in milliseconds:
  - e.g., a loss of signal on an optical link
- The optical layer can handle some faults more efficiently
  - a fiber cut results in the loss of all the traffic streams carried by the fiber
  - without optical-layer protection, each traffic stream will be restored independently by the client layers
  - the network-management system may be flooded with a large number of messages (failure notification, traffic rerouting, etc.) for this single failure
- Fewer entities need to be rerouted if the optical layer can quickly restore the traffic

Fault Management in WDM Mesh Networks

- There are two types of fault-recovery mechanisms:
  - *protection*
  - *restoration*
- If backup resources are reserved in advance-> ***protection scheme***
- If another route and a free wavelength have to be discovered dynamically whenever a failure occurs -> ***restoration scheme***

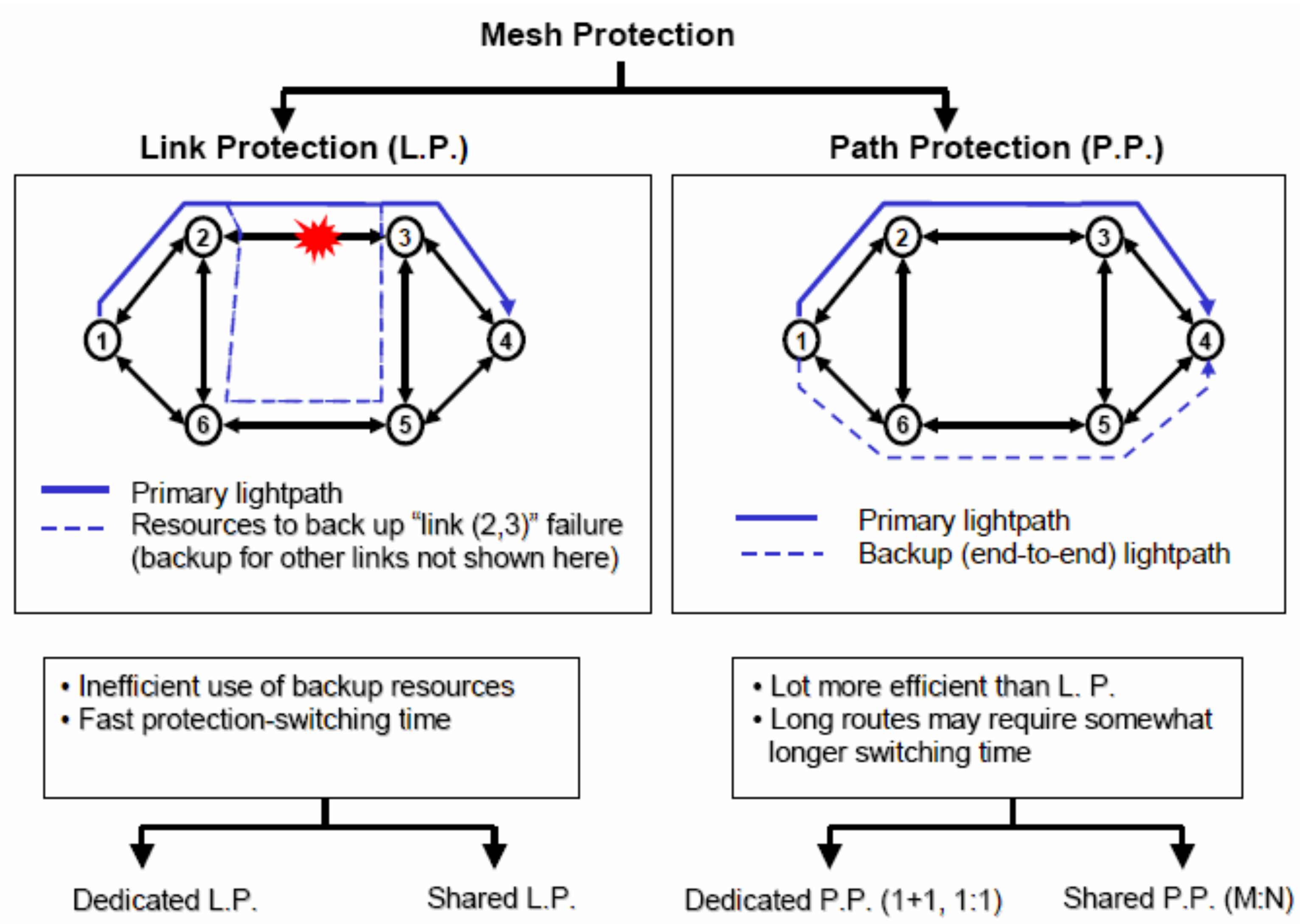
Protection vs. Restoration

- Dynamic restoration schemes are more efficient in utilizing network capacity
  - they do not allocate spare capacity in advance
  - they provide resilience against different kinds of failures (including multiple failures)
- Protection schemes have faster recovery time
  - they can guarantee recovery from disrupted services they are designed to protect against

Path vs. Link Protection

- Protection can be divided into two groups:
  - *path protection*
  - *link protection*
- In ***path protection, the traffic is rerouted through a*** backup route once a link failure occurs on its working (primary) path
  - the primary and backup paths for a connection must be link/node/SRLG-disjoint (depending on connection requirement)
  - no single link/node failure can affect both paths
- In ***link protection, the traffic is rerouted only around the*** failed link
  - new route needs to be also link/node/SRLG disjoint
- Path protection leads to efficient utilization of backup resources
- Link protection provides faster protection-switching time

Path vs. Link Protection Example



Dedicated vs. Shared Protection

- Protection schemes can be:
  - dedicated
  - shared
- In ***dedicated protection, sharing is not allowed between*** backup bandwidth
- In ***shared protection, backup bandwidth can be shared*** on some links,
  - as long as their protected segments (links, paths) are mutually diverse or not in the same SRG
- OXCs on backup paths are not configured until the failure occurs if shared protection is used
- Recovery time in shared protection is longer but it can achieve better resource efficiency than dedicated protection

1+1 Protection (Dedicated)

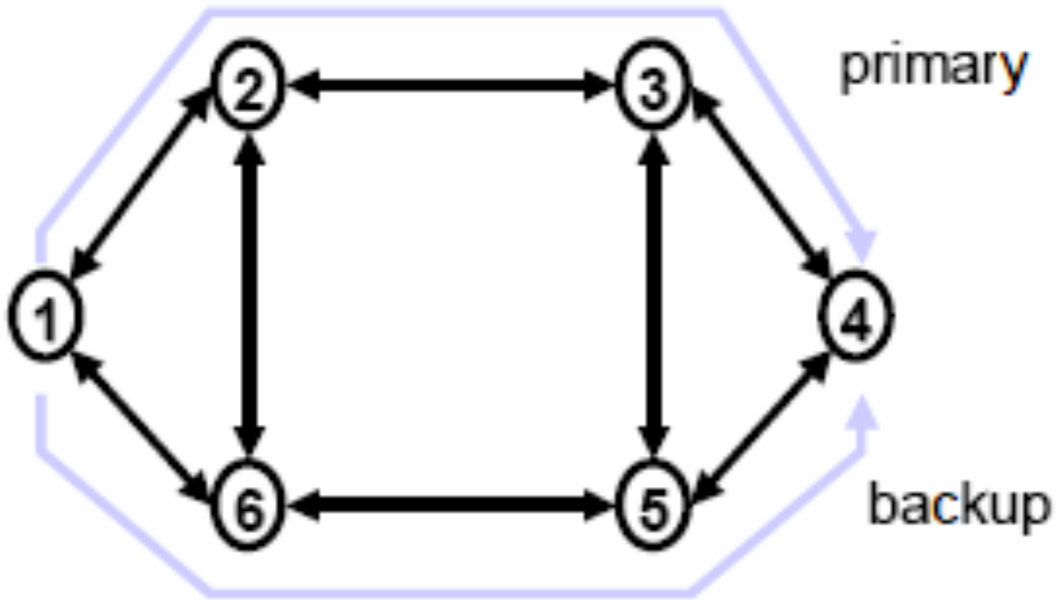
- If traffic is transmitted simultaneously on both primary and backup paths, the destination simply selects one of the two signals for reception
- If one path is cut, the destination switches over to the other path and continues to receive the data
- This form of protection is usually referred to as 1+1 protection
  - provides very fast recovery and requires no signaling protocol between the two end nodes

1:1 Protection

- If traffic is only transmitted on the primary path, the source and destination nodes both switch over to the backup path when the primary path is cut
- This form of protection is referred to as 1:1 protection
  - the backup bandwidth can be used to carry low priority preemptable traffic during normal operation
- Shared protection scheme is also referred to as M:N protection
  - *M primary paths may share N backup paths*

1+1 Protection Example

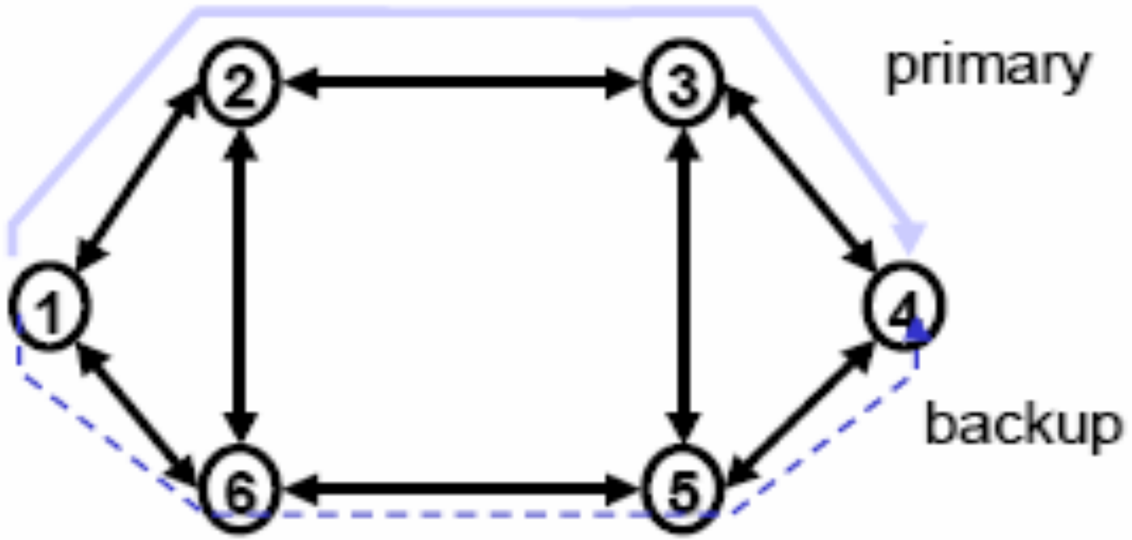
1+1 Protection



Both primary and backup are carrying "live" traffic

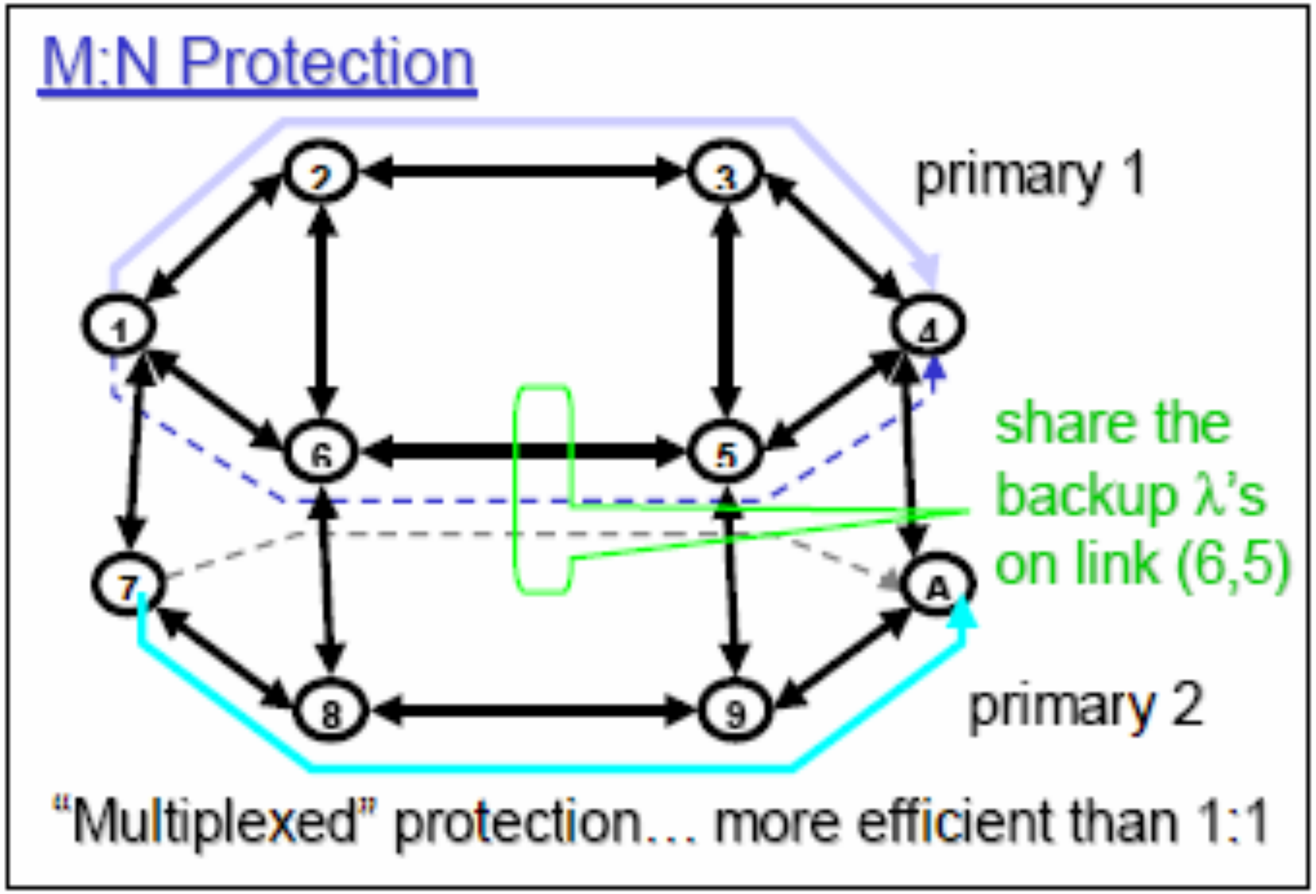
1:1 Protection Example

1:1 Protection

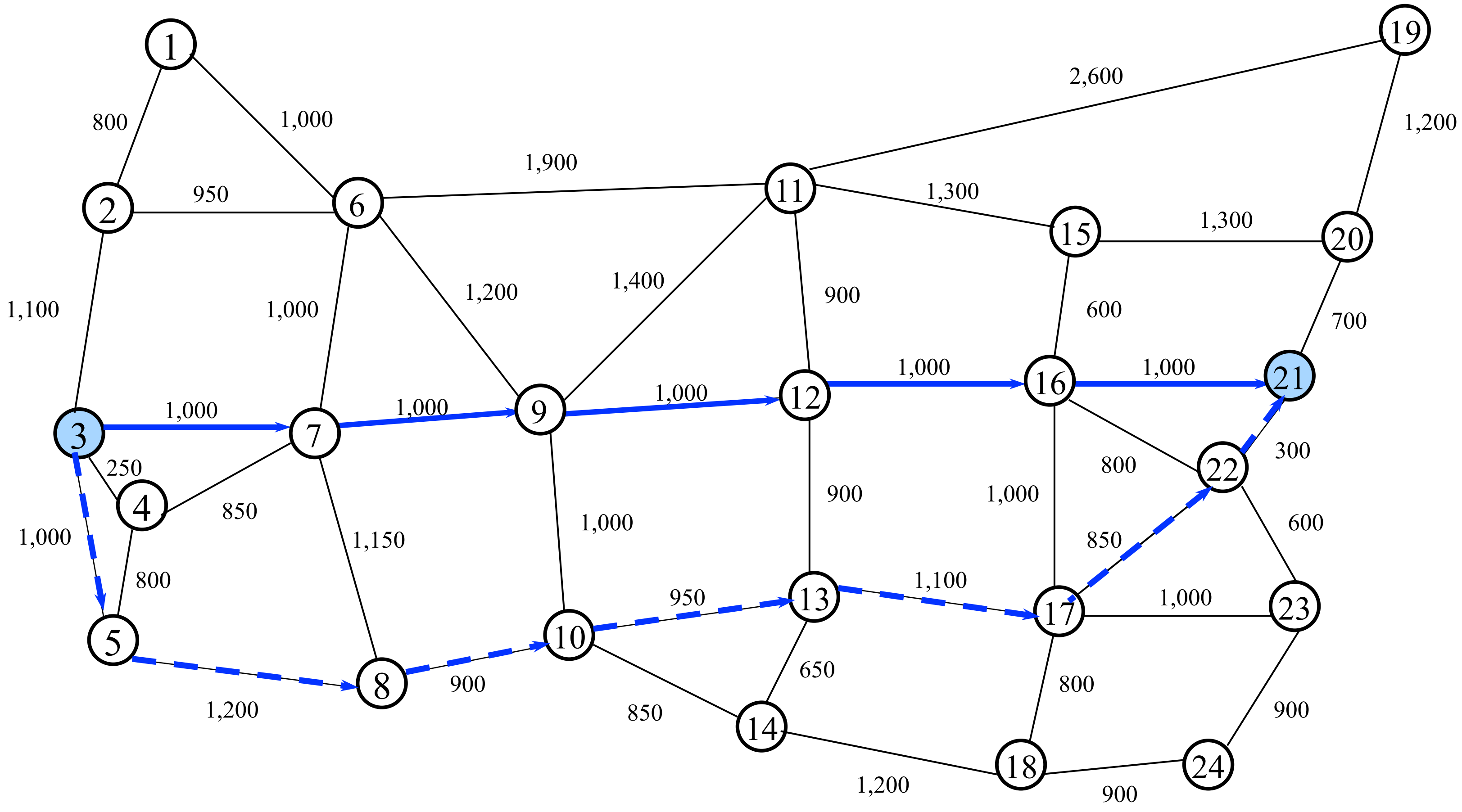


Backup activated after failure detected, can carry other low-priority preemptable traffic

M:N Protection Example

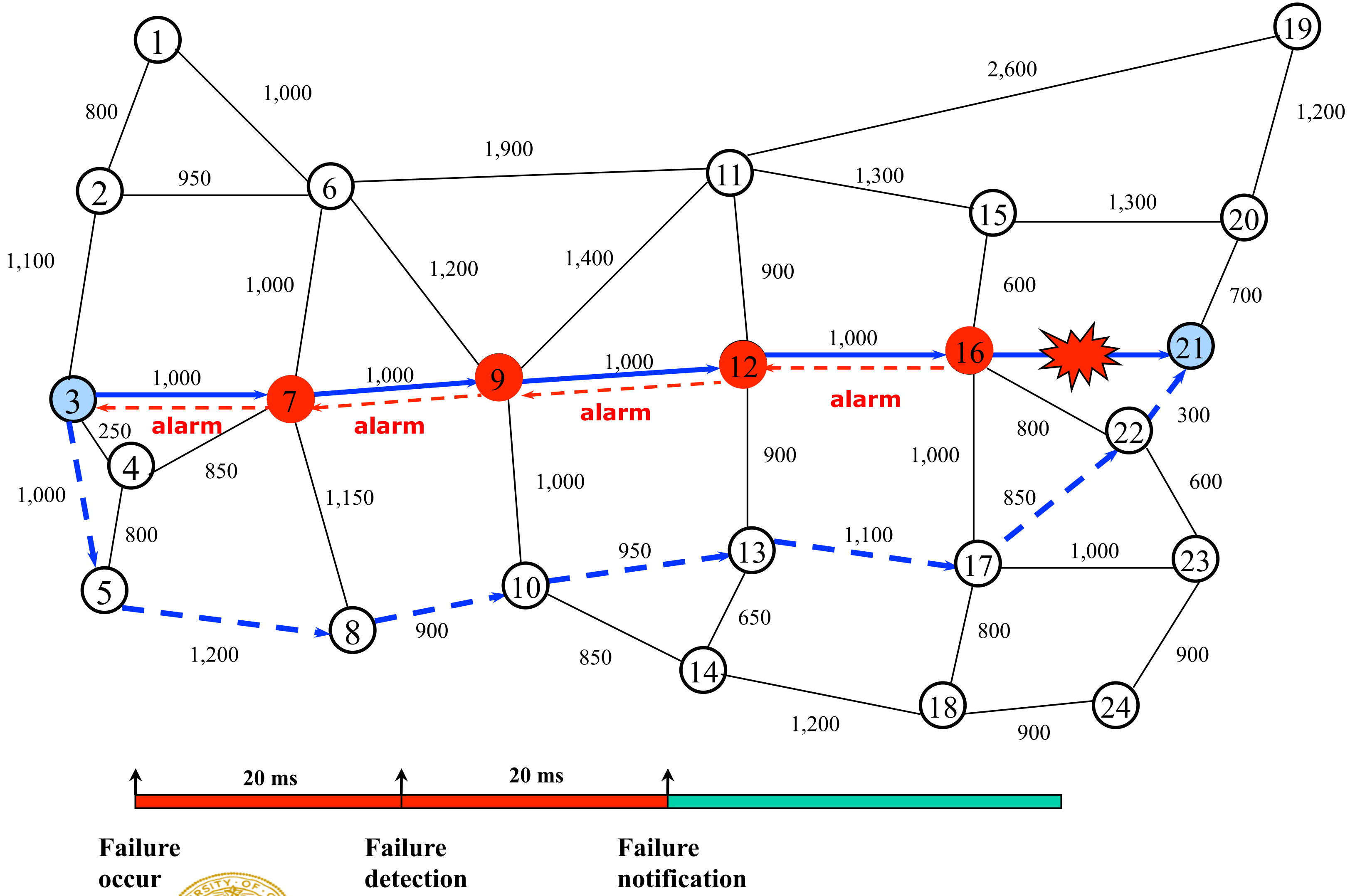


Path protection failure recovery: example

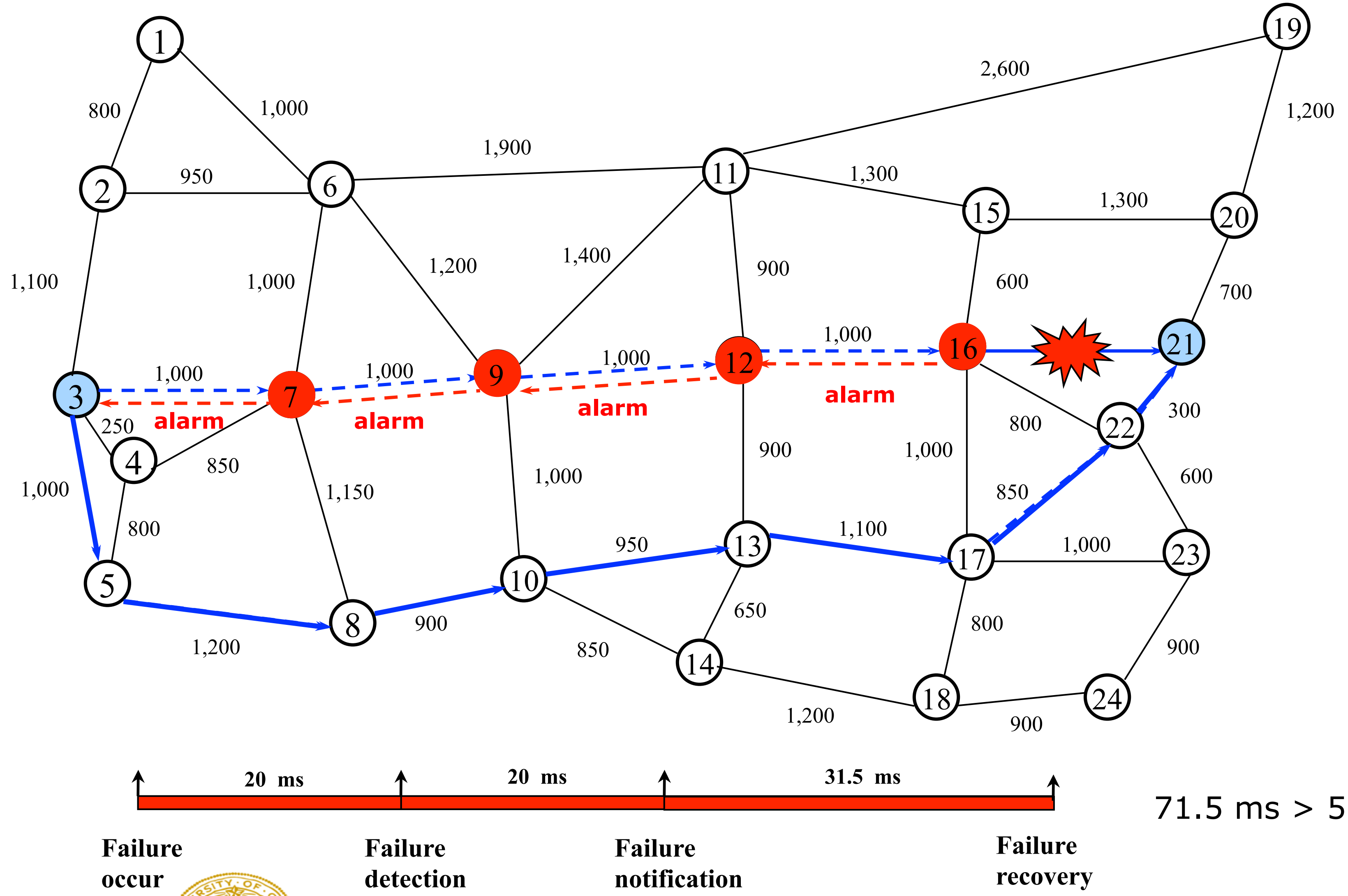


Overall Fiber Distance = 11,300 Km

Path protection failure recovery: example



Path protection failure recovery: example



71.5 ms > 50 ms

Reverting vs. non-reverting

- Protection schemes can be:
  - reverting or
  - non-reverting
- In both schemes, if a failure occurs, traffic is switched from the primary path to the backup path
- In *reverting*, the traffic is switched back to its primary path after the failure on the primary path is repaired
- In *non-reverting*, the traffic stays on the backup path for the remaining service time
- Reverting allows the network to return to its original state once the failure is restored

Reverting vs. non-reverting

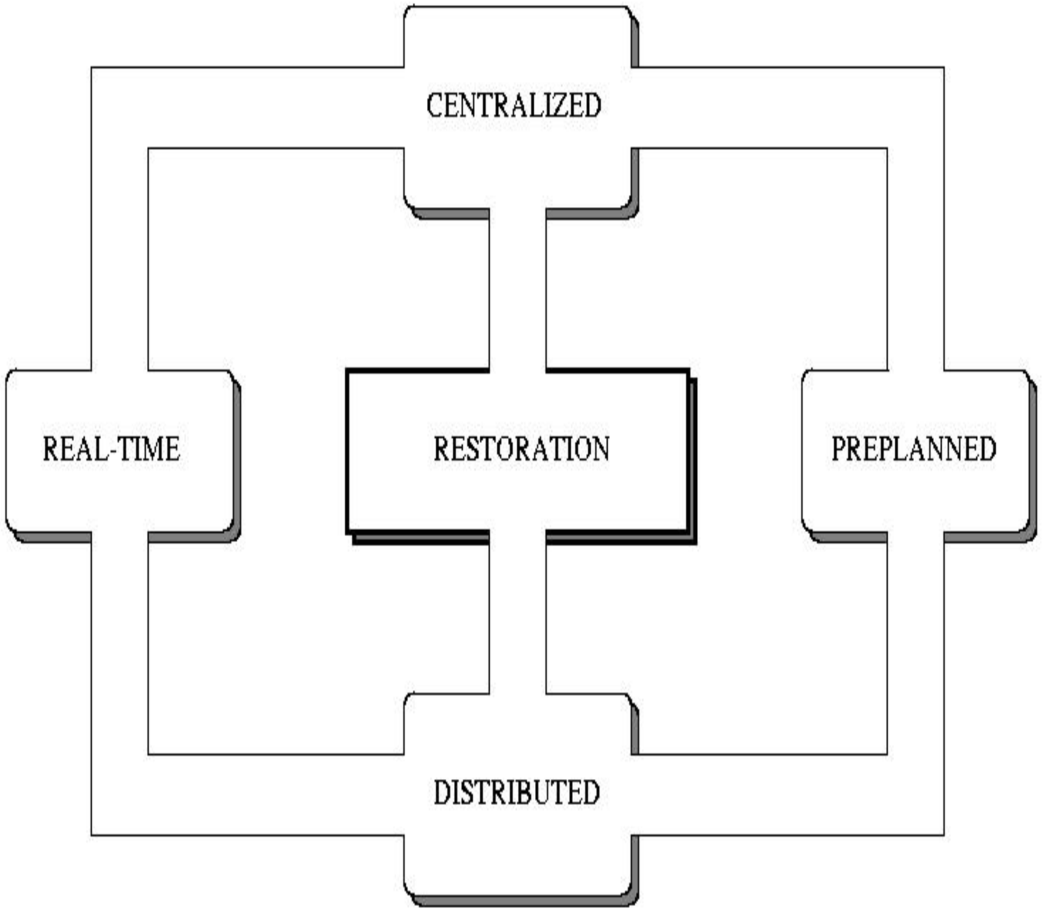
- *Dedicated protection schemes* can be either reverting or non-reverting
- Only reverting may be applied for a *shared protection scheme*
  - since multiple connections are sharing the common backup bandwidth, the backup bandwidth must be freed up as soon as possible after the original failure has been repaired
- Reverting, however, will cause an additional (possible) disruption of the data flow

Restoration

- Restoration can be classified as *link*, *sub-path*, or *path* based, depending on the type of rerouting
- In link restoration, the end nodes of the failed link dynamically discover a route around the link, for each connection that traverses the link
- In path restoration, when a link fails, the source and the destination node of each connection that traverses the failed link are informed about the failure
  - the source and destination nodes of each connection independently discover a backup route on an end-to-end basis
- In sub-path restoration, when a link fails, the upstream node of the failed link detects the failure and discovers a backup route from itself to the corresponding destination node for each disrupted connection

Restoration schemes

- Advantages
  - Adaptable to network (traffic and topology) changes and failure patterns
  - Small spare bandwidth required (< 50%)
- Drawbacks
  - Usually slow (recovery time > 50ms)
  - Coordination required upon failure



Restoration schemes characteristics

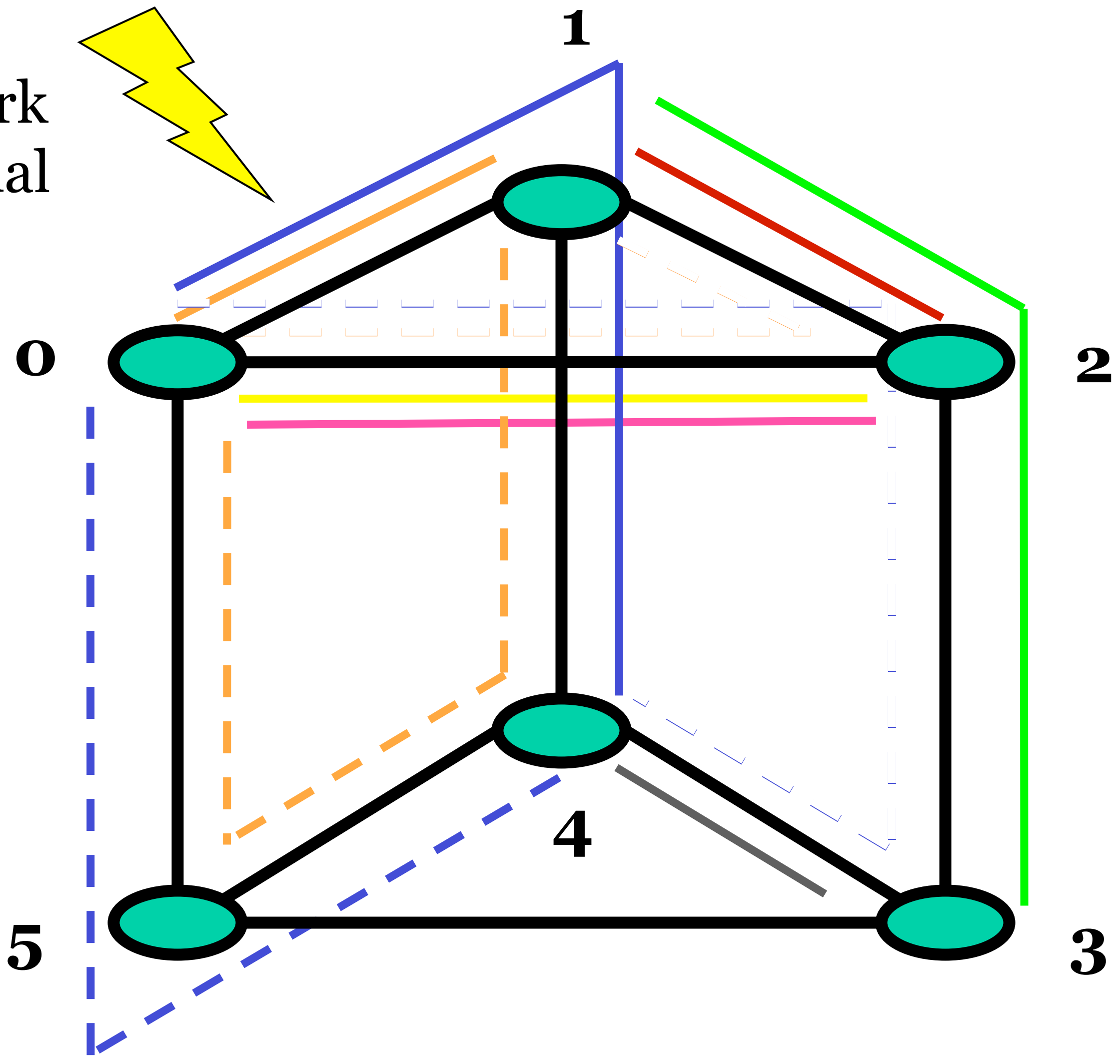
- Centralized Real-Time: paths are computed and spare resources reserved upon failure occurrence
  - central controller with network state global knowledge
- Centralized Pre-planned: paths are pre-computed before failure while spare resources are reserved upon failure occurrence
  - central controller chooses the path for the failed connections based on network state global knowledge and specific failure
- Distributed Real-Time: paths are computed and spare resources reserved upon failure occurrence
  - each node to which connections involved in the failure belong acts independently
- Distributed Pre-planned: paths are pre-computed before failure at each node while spare resources are reserved upon failure occurrence
  - each node chooses the path based on his most updated network state information

Restoration schemes pros and cons

- **Centralized**
  - ☺ Simplicity of a central controller + possible optimal solution
  - ☹ Need for reliable controller + reliable controller communication network
- **Distributed**
  - ☺ High restorability + capacity efficiency
  - ☹ Difficult protocol implementation + high message contention degree
- **Real-time**
  - ☺ High restorability because up-to-date information
  - ☹ Slow recovery time + high resource contention
- **Preplanned**
  - ☺ Fast recovery time
  - ☹ Low restorability because out-of-date information

Preplanned restoration: example

- Test network (average nodal degree 3)



Algorithmic solutions for resilient provisioning

- Fixed routing solutions:
  - Dijkstra Algorithm
  - Surballe Algorithm
- Fixed Alternate routing solutions:
  - K-shortest path
  - K-shortest link-disjoint paths algorithm
- Adaptive routing solutions:
  - Dijkstra algorithm
  - Surballe Algorithm