The Migration Toward the Optical Internet

Lesson 10

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Resilience in IP over WDM Networks

- A network is defined as *resilient* or *survivable* if it provides some ability to recover ongoing connections disrupted by the failure of a network component, such as a line interruption or node failure
- Resiliency in survivable networks is obtained by exploiting *restoration* and/or *protection* schemes

Restoration and Protection

- Restoration
  - upon network failure a restoration scheme dynamically looks for backup paths of spare capacity in the network
- Protection
  - a protection scheme reserves, in advance, dedicated backup paths and wavelengths in the network
- Restoration schemes are commonly available at higher layers (e.g., the IP layer)
- Protection schemes are commonly ised at the physical transport layer (e.g., WDM)

Resilient Schemes in IP over WDM Networks

- In the two-layer IP over WDM architecture each layer can provide its own independent resilient scheme
- Resilience concept is naturally embedded in the IP layer
  - the actual path used to route a packet from source to destination is dynamically found and maintained by the routers
- Protection techniques at the optical layer are just emerging driven by the need for coarse and fast protection schemes

IP Layer Resilient Schemes

- Resilient schemes available at the network layer (e.g., IP/MPLS) have the capability to recover faults and operate at fine traffic granularity
  - Granularity is determined by the protocol traffic unit at that particular layer
- Drawbacks
  - generally slow
  - require online processing upon failure occurrence
- Network layer resilient schemes
  - IP dynamic routing
  - MPLS protection switching

IP Dynamic Routing

- With IP dynamic routing reachable active routers are are found dynamically, thus adapting IP routing to possible network faults
- The task is accomplished by exchanging between adjacent routers control messages used to update routers' routing tables (e.g., LSAs)
- IP packet get therefore dynamically rerouted around link and node failures
- IP dynamic rerouting guarantees networkwide survivability, independent of the underlying physical network

IP Dynamic Routing Fault Detection

- Faults can be detected by the routers either explicitely or implicitely
- Explicit fault detection
  - faults are detected at local level and signaled to neighboring routers through regular exchange of routing protocol control messages (ICMP)
- Implicit fault detection
  - based on expiration of timers such as KEEPALIVE (TCP) and HELLO (IP) messages

IP Dynamic Routing Fault Recovery

- Once a router detects a line fault it recalculates the affected routes and updates its routing tables
- Occurred changes are propagated through UPDATE messages such as OSPF LSA and Border Gateway Protocol-4 (BGP-4)

IP Dynamic Routing Advantages and Drawbacks

- Advantages
  - efficient use of network spare resources
  - flexible to topological changes
- Drawbacks
  - usually slow (from tens of seconds to minutes)
  - unpredictable behavior

IP Dynamic Routing Enhancements

- Equal Cost Multipath Forwarding (ECMF)
  - router relies on more than one path for transmitting packets sharing a common destination
  - in case of failure, a fraction of packets are guaranteed to flow to the destination until the router routing table is update with the recalculated routes
- Partitioning the network into multiple areas as defined in hierarchical link state routing protocols
  - update are confined to the affected area minimizing the network reconfiguration convergence time
- Increase frequency of HELLO messages or implementing rapid rate pinging through ICMP ECHO request
  - it permits to decrease the failure detection time

MPLS Protection Switching

- MPLS protection switching is an alternative approach to circumvent the latency drawback of dynamic rerouting
- MPLS protection switching is enabled through a hierarchy of LSPs
- Protection entities can be set up either dynamically or on in a pre-negotiated way

Dynamic MPLS Protection

- Protection entities dynamically set up, restore traffic based on
  - failure information
  - bandwidth allocation
  - optimized reroute assignment
- LSP crossing a failed line or Label Switch Router (LSR) are reestablished using reservation signaling

Prenegotiated MPLS Protection

- Working LSPs have pre-established protection paths
- The pre-established protection path is node and link disjoint from the working path
- Network resources of the protection path can be
  - reserved beforehand (unused unless failure occurs)
  - dynamically allocated to low-priority traffic that is allowed to use them in absence of network failure

MPLS Protection Granularity

- Both MPLS protection switching schemes can be performed
  - on a line basis → link rerouting
    - only the portion of the LSPs around the failed line is rerouted
  - on a path basis → edge-to-edge rerouting
    - the entire failed LSPs are independently rerouted

MPLS Protection Switching Scheme Comparison

- Dynamic protection vs. pre-established protection
  - increases resource utilization
  - requires longer restoration time
- Link rerouting vs. end-to-end rerouting
  - faster
    - because in end-to-end rerouting the failure notification must reach the head-end of all the LSPs
  - link rerouting not well suited for handling node failure

WDM Layer Resilient Schemes

- Both OCh and OMS sublayers feature
  - dynamic restoration
  - preplanned protection
- Main differences between OCh and OMS resilient schemes is represented by the granularity at which they operate
  - OCh schemes protect individual lightpaths
    - this allows selective recovery of optical line terminal (OLT) failures
  - OMS resilient schemes work at the aggregate signal level
    - all the lightpaths present on the failed line are concurrently recovered

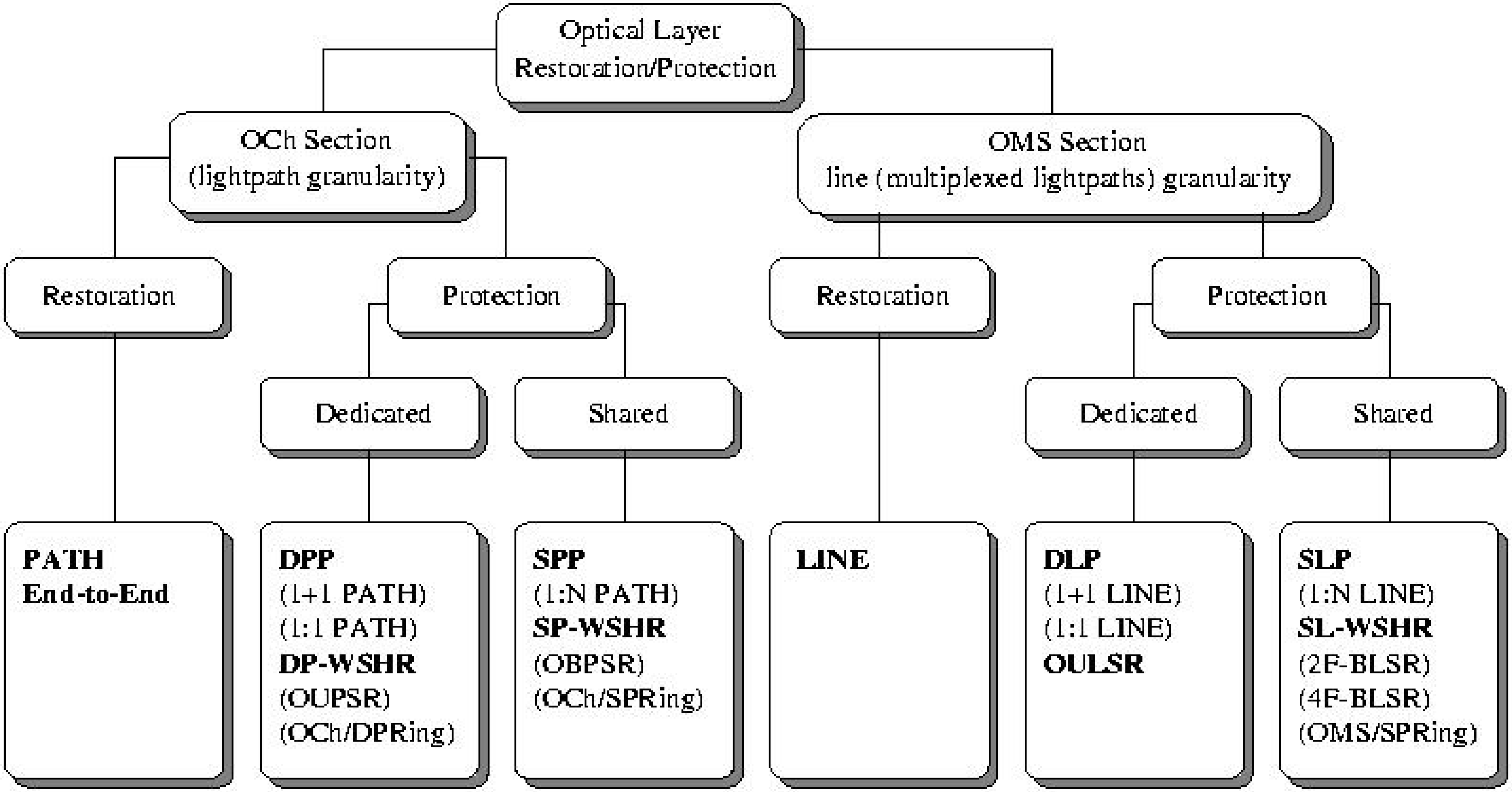
WDM Resilient Schemes (2)

- Like in higher layers
  - restoration schemes
    - more efficient from a capacity viewpoint
    - relatively slow (recovery time on the order of seconds or minutes)
  - protection schemes
    - less capacity efficient
    - fast (recovery time on the order of seconds or minutes)

Terminology

- working lightpath
  - default path of light established between a source-destination pair absent a network failure
- protection wavelength
  - spare channel that may be used in case of network failure
- protection lightpath
  - concatenation of protection wavelengths along a path

Optical Layer Protection and Restoration Schemes

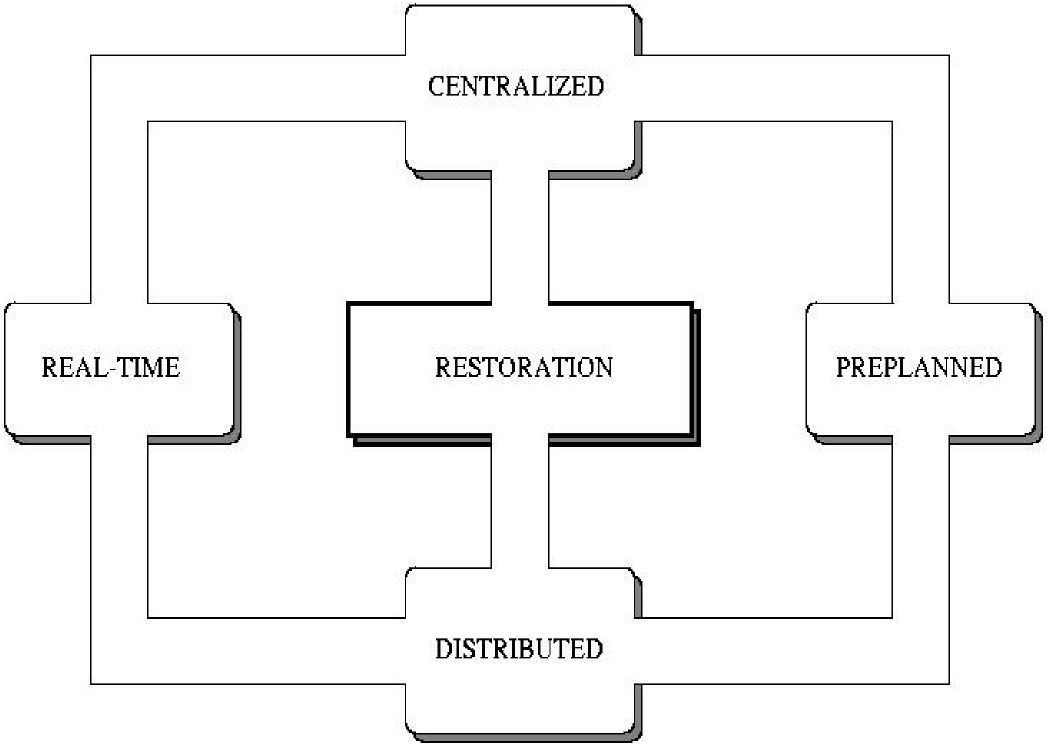


Optical Layer Restoration

- OCh Path restoration
  - upon network failure each affected working lightpath is dynamically replaced by a protection lightpath
  - the protection lightpath is computed using either a centralized or distributed approach
- OMS line restoration
  - an alternative route is found to locally divert all affected working lightpaths around the faulty line
  - this scheme is triggered by the failed line end nodes which make use of a distributed algorithm to dynamically discover the alternative route

WDM Restoration

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



Restoration Scheme Characteristics

- **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

Optical Layer Protection

- OCh protection scheme is also called *path protection*
- OMS protection scheme is also called *line protection*
- In both schemes protection (spare) resources can be
  - dedicated
    - the spare resource is dedicated to a single working lightpath
  - shared
    - the same spare resource may be used to provide protection to multiple working lightpaths
- OCh and OMS protection schemes are available in *mesh* and *ring* network topologies

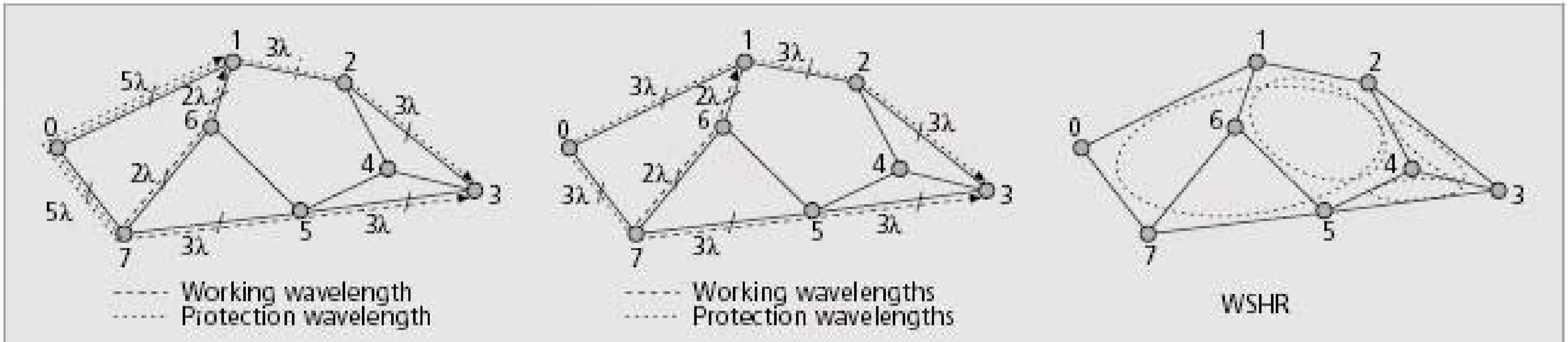
Dedicated Protection

- 1+1
  - the source node transmits on both the working and protection lightpaths simultaneously
  - destination node keeps monitoring both lightpaths dynamically choosing the signal with the best performance (e.g., signal-to-noise ratio)
- 1:1
  - transmission occurs on the working lightpath only
  - the protection lightpath may be used to transmit low-priority traffic
  - upon failure of the working lightpath both the source and destination nodes switch over the protection lightpath
  - low-priority traffic is preempted

Shared Protection

- Also referred as 1:N
- Allows spare wavelengths to be shared by a number of working lightpaths
- In case of a fault each disrupted transmission is switched over the protection wavelengths
- The operation requires signaling
  - to notify network nodes of the new transmission paths
  - to make sure that the protection wavelengths on the various fibers are correctly interconnected to form the required protection lightpaths
  - once spare resource is used to protect a working lightpath it will not be available to protect the other working lightpaths until the original working lightpath is established

Mesh Protection Schemes



(a) DPP (b) SPP (c) Multi-WSHR covering

Dedicated Line Protection

- DLP
  - reserves protection wavelengths between the end nodes of each line utilized by working lightpaths
  - DLP may require more spare capacity allocation than other scheme
  - DLP can be faster than DPP
    - due to shorter failure notification

Shared-Line Protection

- SLP
- Also termed 1:N line protection
- applies the SPP technique locally to the faulty line
- better spare resource utilization than DLP
  - becuase of resource sharing
- recovery time generally faster than SPP
  - because of locally limited signaling

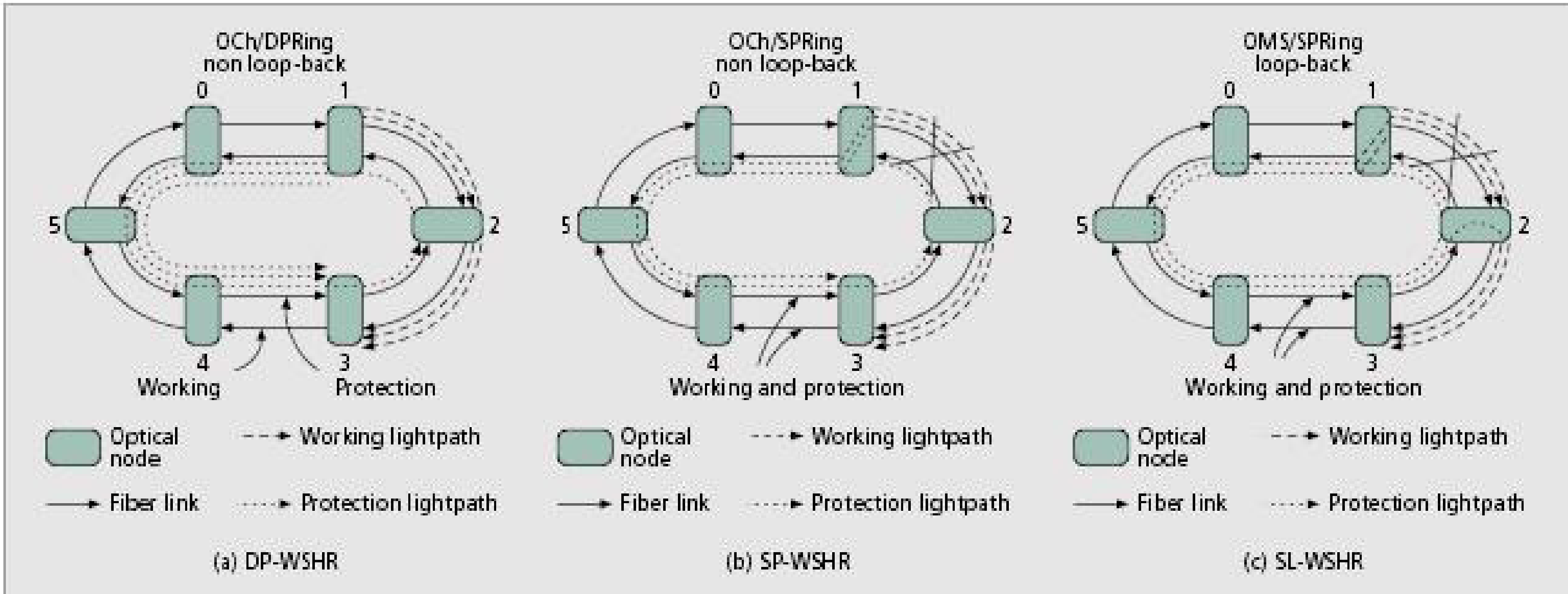
Dedicated Path Protection (DPP)

- DPP
  - fast
    - 1+1 DPP just requires that the receiving node switches to the protection lightpath
  - robust in the face of multiple failures
    - the failures must not occur simultaneously in lines belonging to the working and protection lightpath of the same connection
  - low degree of management complexity
  - does not efficiently use spare resources

Shared-Path Protection

- SPP
- Also termed 1:N protection
- Protection wavelengths are shared by a number of line and node-disjoint working lightpaths
- More efficient utilization of spare resources than DPP
- more complex control
  - signaling required between source and destination nodes
- longer recovery time
  - on the order of 100ms

Ring Protection Schemes



Dedicated-Path-Switched WSHR

- Also called
  - Optical Unidirectional Path-Switched Ring (OUPSR)
  - OCh dedicated protection ring (OCh/DPRing)
- It is the DPP equivalent for ring networks
- recovery time fast
  - order of ms or fraction of ms
- total protection wavelength mileage equal or larger that the one required in the other OCh and OMS ring protection schemes

Optical Unidirectional Line-Switched Ring

- OULSR
- Similar to DP-WSHR
- it utilized two counter rotating fibers
  - one for working lightpaths
  - other for protection lightpaths
- because line protection scheme all lightpaths passing through the failed line are jointly switched over the protection fiber
- OULSR vs DP-WSHR
- same wavelength mileage
- due to line switching employs less expensive devices
- similar recovery times

Shared-Path WSHR

- SP-WSHR
  - also termed Optical Bidirectional path-switched ring (OBPSR)
  - or OCh shared protection ring (OCh/SPRing)
- SPP equivalent in ring networks
- scheme's peculiarity is *nonloopback* switching
- each working lightpath is switched to the protection lightpath at its source node
- the recovered traffic reaches the destination node only along the protection lightpath
- SP-WSHR si the most efficient among the WSHR protection techniques in terms of spare resource utilization
- it requires complex control and signaling

Shared Line-Switched WSHR (SL-WSHR)

- physically implemented with
  - two fibers (optical two-fiber/BLSR, O-2F/BLSR)
  - four fibers (optical four-fiber/BLSR, O-4F/BLSR)
- in either case working lightpaths and protection wavelengths may be carried using both directions of propagation
- peculiarity is *loopback* switching
- upon failure the working lightpaths are switched, at one failure end, to the protection wavelengths of the counter-rotating fiber
- when they reach the other failure end they are looped back along their original working wavelengths to reach their destination nodes
- SL-WSHR characteristics
  - simple
  - fast (recover time on the order of tens of milliseconds)

Coordination between IP and WDM Layers

- Coordination between resilient schemes si required to avoid multiple scheme concurrent activation
- Coordination commonly achieved through *escalation strategies*
- Escalation strategies sequentially activate the different resilient schemes starting from either the lowest or highest network layer
- Escalation strategies may be governed by
  - explicit messaging between the different layers
  - arbitrarily setting failure detection and recovery times
  - not coordinated