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End-to-End Self-Healing Network

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I. Introduction

The recent technology trends have led to high speed fiber transport links, high capacity network systems, and multimedia services. These trends increased the vulnerability of the network to both hardware and software failures bacause any failure events can affect hundreds of thousands of services. Protecting this large quantity of service traffic from network failures is a key requirement for the ongoing development and deployment of the high capacity network systems.

End-to-end self-healing is the ability of a network to reconfigure itself around failures on an end-to-end basis. The goal is to respond to all service affecting events before the customer is affected.

This paper describes self-healing schemes on the end-to-end network architecture. It provides possible schemes for the current network and the future network as the network evolves to the high capacity broadband ATM network. Section 2 provides the end-to-end network architecture overview. Section 3 covers the self-healing strategies in the end-to-end network architecture. Section 4 provides concluding remarks.

II. End-to-End Network Architecture Overview

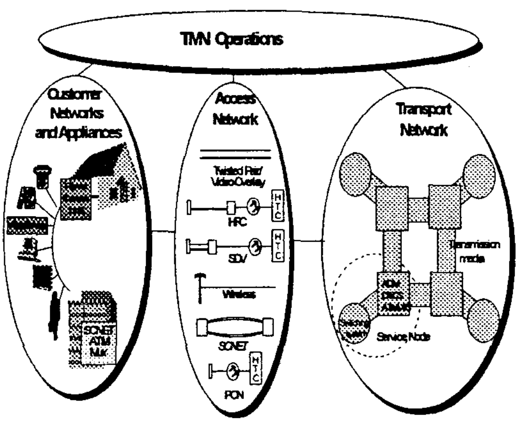
The overall end-to-end self-healing network architecture is divided into three distinct domains: Customer Premesis Equipments (CPEs), access, and transport. Figure1 is a functional view representation of the end-to-end network architecture vision.

The CPEs are equipment at the customer premises, ranging from telephones to PBXs and from LANs to campus wide networks. ATM muxs at the CPEs will allow users to configure their subscriptions as desired.

The access network domain collects traffic from a set of end-user CPEs and multiplexes it to one or more desginated nodes in the network. From that node a different controller routes the traffic to a destination access domain.

Today, access to the transport network is based on twisted pairs for the residential. They are gradually integrated into broadband access options such as HFC and SDV. Wireless access is also an option. Business access will use SONET/ATM rings.

The transport network is composed of those set of nodes that are not directly connected to end-user nodes. The major function of the transport network is to consolidate and route traffic such that a minimum number of physical links have to be established between access domains.



〈Fig. 1〉 End-to-End Architecture Vision(Functional View)

Transport network domain is defined as a layered model in CCITT Recommendation G. 803[1]. This transport layer model is divided into circuit layer network, path layer network, and transmission media layer network.

The circuit layer network is a network that establishes end-to-end circuits(e.g., 64 kbps, packets, or virtual circuits) as a service unit between users in accordance with the user's requirements.

The transmission media layer network is a network that establishes transmission capacity between path layer network equipments such as cross connect systems or add/drop multiplexers.

The path layer network is a network that bridges between circuit layer and transmission media layer network, and provide a logical path connections between circuit switch pairs. This path layer network plays an important role in constructing flexible and reliable transport network. The path layer network is supported by either cross connect systems in mesh networks or Add/Drop multiplex systems in rings.

Equipments supporting circuit layer and path layer are often called as a service node.

The Telecommunication Management Network(TMN) integrates all operation, administration and maintenance functions for the network and for provision of services.

We will describe the appropriate self-healing strategies by each domain in the next section.

III. Self-healing strategies in the end-to-end network architecture

1. Self-Healing Strategy Components

The following self-healing strategies and the corresponding architectural elements for responding to failures exist now or can be developed in the future network.

1) *Protection switching within a system for circuit pack failures. This is always the first level self-healing response.*
2) *Facility restoration using dual feed techniques(protection switching onto diverse facilities)*
3) *Service restoration with intelligent network equipments(Cross Connect Systems, Add/Drop Multiplexer Systems)*
4) *Traffic restoration by reroutes onto unaffected trunks or Virtual Paths(Facility Diverse Routing)*

The overall strategy is comprised of elements selected from many of the listed capabilities depending on customer's reliability requirements. The guaranteed level of service that a network provider supplies to each customer depends on how much the customer is willing to pay for the service.

2. Self-healing in the CPEs

The CPEs failures are a large fraction of cusi3.tomer downtime. The strategy for responding to an CPEs failure should be integrated with access failures, especially in the loop section. The CPEs must be able to switch to an alternate direction of transmission upon detection of the failure, and also to select between more than one incoming direction of transmission. Two diverse paths can go from a CPE to an access node. The transmitter transmits two identical streams of data over two diverse paths. The receiver examines the two incoming data streams and selects the best of two streams for processing. If a physical link is failed, the data is switched to the alternate path.

ATM CPEs can be dual homed by using preplanned backup Virtual Paths(VPs) to the network access connection. Using end-to-end VP protection switching offers a way to achieve a high reliability level to the entire ATM VP connection without a single point of failure although guaranteering end-to-end route diversity remains a difficult task from the operations point of view.

CPEs wiring is another significant source of a failure. Diverse wiring paths in the building provide significant improvement in reliability. Similarly, a LAN in a campus wide networks will need some form of diversity.

The rate of failures in CPEs can be reduced by increasing the reliability of the equipment. This can include, for example, duplication of the processor in the CPE systems.

3. Self-Healing in the Access Network

The access connection is usually provided by the Local Exchange Carrier(LEC), so the primary focus of the self-healing strategy in the access network is directed towards LEC access. LECs are rapidly migrating their transport networks from T1 carrier to fiber systems with much higher reliability. The access through LEC networks can be broken down into three parts : from the CPEs to a LEC, interconnected LEC networks, from the LEC to the transport network service nodes. Interconnected LEC networks are often called as a transfer network or access transport network.

Self-healing in the interconnected LEC network can be performed using techniques such as add/drop fiber rings. Today's LECs have fiber ring based access network in virtually every major metropolitan area. There are several self-healing ring architectures proposed. Details will be described in the transport network.

Failures between the LECs and the transport network service nodes require protection switching arrangements for true end-to-end reliability.

4. Self-Healing in the Transport Network

The transport network can be divided into multiple subnetwork domains. For fast restoration, it is very critical to deploy the subnetwork domain based transport network architecture where each domain executes self-healing algorithms indepent of other domains.

Self-Healing in the each layered network can be performed independently or/and coorperatively to achieve the end-to-end self-healing network. Self-healing strategy tradeoff between physical transmission media layer network and path layer network is a key issue to the network service providers. We describe possible schemes and provide advantages and disadvantages of each schemes in the Table 2.

1) Self-Healing in Circuit Layer Network

Some users, mainly large business, may be willing to pay a premium for a level of reliability that goes beyond protecting against access and physical link failures. These users are concerned about the consequences of catastropic failure of a switching node. Multihosting or multihoming configurations can dramatically reduce vulnerability to such failures.

Multihosting allows an access to distribute its lines between several switches, therby reducing the impact of a switch failure. If a switch fails, the lines connected to other switches will still function. Multihoming allows an access remote to dynamically rehome, or reassign, lines from a failed switch to a working switch and have these lines continue to function. This protects lines from either total or partial switch failure, where caused by accidents, technical problems, or natural disasters such as fires, earthquakes, and etc. Multihoming is based on the use of shared protection access rings. If the switch to which an access has connected its lines fails, the access can rehome the lines to a backup switch on the ring.

2) Self-healing in Transmission media layer network

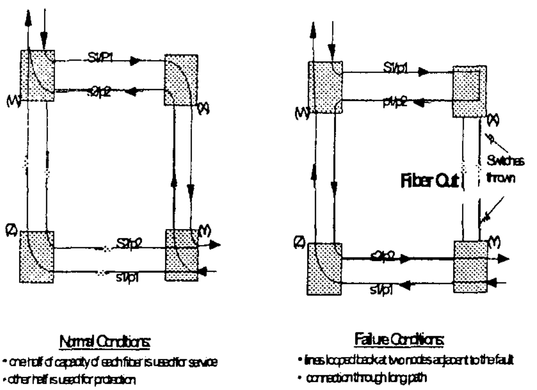
Self-Healing at the physical layer can be performed either linear mode or ring mode.

The linear mode is typically called as a 1 : N protection switching, which means that there is one protection channel for every N(an integer) working channels.

The ring mode based on SONET/SDH provides redundant bandwith so distributed services can be restored following network failure, with no external coordination. There is a ring for carrying traffic, but there also is another ring in opposite directions for protection. When a transmission line is faulty, the entire line is switched out to a protection loop at the failure boundaries. This is ofen called as Bidirectional Line-Switched Rings(BLSR). The BLSRs are very efficient when traffic patterns require a balanced traffic distribution between the nodes of the ring. The BLSRs can be implemented with two or four fibers[2].

Two fiber BLSRs require only two fibers for each span of the ring. Each fiber carries both working and protection channels. On each fiber, half the channels are defined as working channels and half are defined as protection channels. The working channels in one fiber are protected by the protection channels traveling in the opposite direction in the other fiber. This protection mechanism is defined as ring switching. The reliability of two fiber BLSRs is analogous to 1 : N protection(In the figure 2, N=4) . When one failure causes a ring loopback switch, no other failure can use the protection loop.

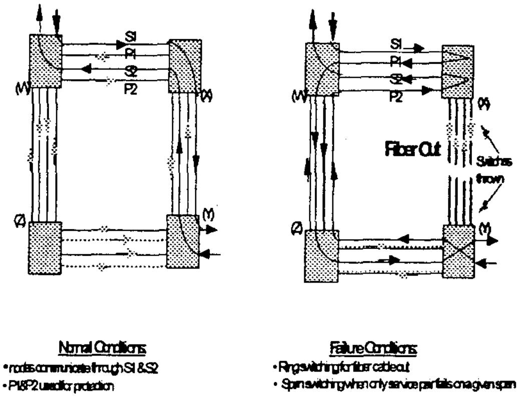
However, it has overall startup cost advantage over the four fiber ring. The two fiber BLSRs are very similar to a point-to-point VP ring architecture in terms of sharing capacity on both fibers. The BLSRs use point-to-point SONET/SDH paths(i.e., STS-N), whereas the ATM uses point-to-point VPs. Thus, the evolution of the point-to-point ATM VP ring from the SONET/SDH BLSRs may occur natually to use the inherent benefit of the flexible bandwidth management by using VPs in the ATM network.



⟨Fig. 2⟩ Physical Layer Restoration 2fiber bidiredional ring(ELSR)

Four fiber BLSRs require four fibers for each span(the segment between two adjacent ring nodes) of the ring [Figure 3].

Working and protection channels are carried over different fibers. A single line failure can be protected by normal span protection. Only complete fiber cut or node failures need to be protected by a ring line loopback function. The reliability of four fiber BLSRs is analogous to 1 : 1 protection. On the other hand, the four fiber BLSRs have higher start-up cost than the two fiber BLSRs. ATM network restoration can also be performed by using the four fiber BLSRs.

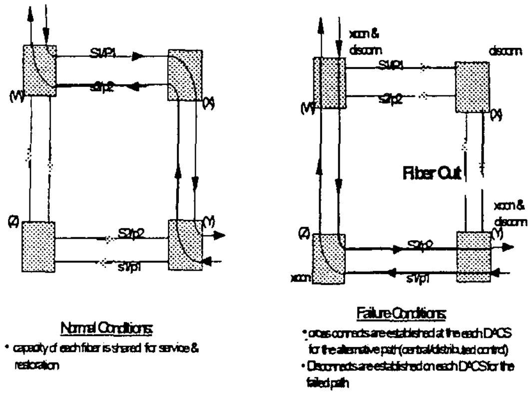


⟨Fig. 3⟩ Physical Layer Restoration 4fiber bidireotionel ring(ELSR)

Compared to meshed network architecture, the BLSRs have benefits such as simpler control schemes and fast restoration(less than 60 ms) at the expense of limited service growth potential. However, the BLSRs require dedicated hardware and facilities, and provide the same level of availability for all traffic, making them inherently bandwidth-intensive. When the ring capacity is exhausted, system upgrade could become difficult and expensive. Also, it is not practical for any network to be just one big ring. In reality, rings must mesh across different rings so that traffic can pass from one to another. In the next section, we will describe more flexible self-healing schemes in the meshed network.

3) Self-Healing in Path Layer Network

Self-healing in the path layer network can be achieved by either centralized control scheme through the Operating Support System



〈Fig. 4〉 PathLayer Restoration Oross Comeot Systems

(OSS) or distributed control scheme[Figure 4].

In the centralized control scheme, the OSS computes the restoration path for each failed path when any facility failures are reported from the cross connect systems. Considering the large number of tasks that the OSS must perform till it sends an alternative path to the cross connect systems, the centralized control schem is not recommended for network that require very high speed restoration.

There are three alternative approaches in the distributed control scheme in terms of the spare bandwidth assignment and topology update aspects. All three schemes are discussed and their advantages and disadvantages are summarized in the Table 1.

(i) Dedicated resources : not only are the routes fixed, but the unused capacity on them is allocated to possible failures.

(ii) No dedicated resources : neither the route nor the capacity is fixed. In a failure, topology update algorithms are employed for finding extra capacity to reroute failed traffic[4].

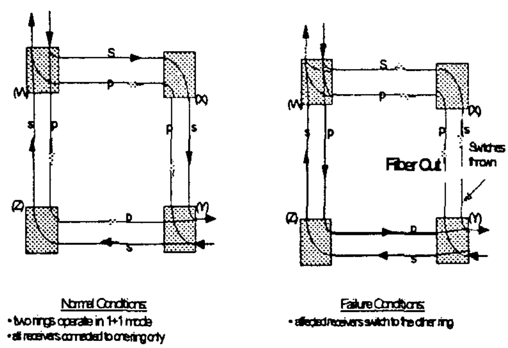
(iii) Semi-dedicated resources : the routes are fixed, spare capacity is searched for in case of a failure[5].

Case(i). Dedicated resources :

Unidirectional Path Switched Rings(UPSRs) and ATM VP protection switching are in this category.

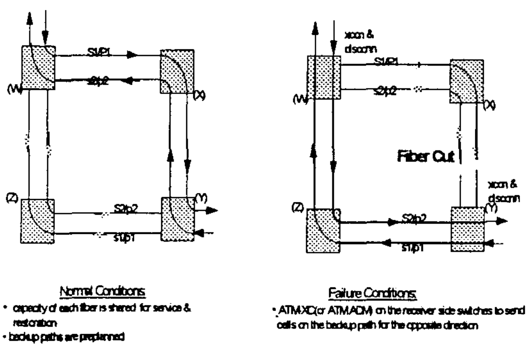
Figure 5 shows the operations of UPSR[3]. With UPSRs, traffic is directed to two diverse routes between source and destination. Transmitter is bridged onto two separate fibers. Traffic flows clockwise on one fiber and counterclockwise on the other fiber. The receiver selects the best signal. No receiver-to-transmitter control mechanism is necessary for the protection switch to occur. However, if the traffic patterns require a uniform distribution of data around the ring, for example when multiple central offices are connected together, then the transport capacity will be saturated very quickly. It is best suit for the homing traffic like access transport network.

ATM restoration using UPSRs can be performed at the STS-3nc(where n is a positive integer).



〈Fig. 5〉 Path Layer Restoration 2fiver unidiredional ring(UPSR)

As shown in Figure 6, for each path, one allocates backup path with full bandwidth for all possible failures. Then, whenever a failure is detected, the corresponding end ATM cross connect systems(ATM-XCs) immediately reroute the failed path. This method does not require any search in real time, and therefore it is very fast, and does not require much processing. On the other hand, it requires allocated capacity and storage for reroute tables at the ATM-XCs. This scheme is recommended for the small subnetwork domain(e.g., VP ring) or portions of the large mesh network domain for only expensive services.



〈Fig. 6〉 Path Layer Restoration : ATMVP protection sw(mesh/ring)

Case (ii). No dedicated resources :

When neither the route nor capacity is fixed, both need to be searched by using topology update algorithms such as the well-known flooding algorithm. The traffic between any two nodes in the network will not necessarily be symmetrical due to the presence of data transmission, or multi casting, and broadcasting type of operations. Therefore, link failures need to be determined at both ends of a failure, and the information needs to be propagated to the corresponding source nodes. This method generates many messages in the network, and is therefore limited to restoration schemes where the source and destination nodes are not widely separated, i.e., local restoration. This scheme can be applied to both SONET/SDH and ATM networks.

Case (iii). Semi-dedicated resources : In this scheme, the alternative backup path is preplanned and the required capacity is serached from the shared bandwidth pool. This is a possible scheme only in the ATM network using the characteristic of the independence of routing and capacity allocation.

〈Table 1〉 Comparison of distributed control alternatives

Schemes	Advantages	Disadvantages
Dedicated Resources	No search is required in real time (protection switching), Unified bandwidth optimization for service and self-healing[6]	Large storage requirement for both capacity and routing map.
No Dedicated Resources	No routing map storage is required. Appropriate for local restoration	Difficult for long path and node failure restoration. More complecated control
Semi-Dedicated Resources	Spare capacity is shared. Complete restoration with one way message transfer	Robust backup VP design is required. Complecated backup VP reconstruction. Large map storage is required.

〈Table 2〉 Summary of self-healing schemes in the transport network architecture

	2-fiber BLSR	4-fiber BLSR	UPSR	DACS based self-healing(mesh/ring)	ATM based self-healing(mesh/ring)
Restoration mechanism	Line loopback	Line loopback	SONET/SDH path switching	Path cross connects	Path cross connect or VP protection switching
Advantages	Faster restoration(less than 60ms)			Efficient bandwidth management along with restoration. Applied to both ring and mesh networks	Flexible granularity for the bandwidth management. VP ring is a compromise of the SONET/SDH and ATM technology
	Service channel reuse that gives it a capacity advantage over UPSRs with fairly evenly distributed traffic		Simpler control for protection switching to occur		
	Overall startup cost advantage over 4 fiber BLSR	Span protection(1x1 protection)			
Disadvantages	Only STS-3nc(n is an integer) for ATM traffic, Limited service growth potential			Overall self-healing performance is slower than SONET/SDH rings	
	1xN(N is the number of nodes in the ring)	Higher startup cost over 2 BLSRs	Dedicated service capacity		
Beneficial application area	Best for evenly distributed traffic	Best for evenly distributed traffic, High growth network, Span protection	Access loop(hubbed demand traffic pattern)	Large networks, inter ring circuits for which 60 ms restoration requirement is not critical for node failures	Service based restoration requirements with effective bandwidth management, multiple S/D routing for service

IV. Concluding Remarks

We presented self-healing schemes in the end-to-end network architecture. The overall end-to-end self-healing network architecture is divided into three distinct domains: CPEs domain, access domain, and transport domain. It is very important for each domain to implement appropriate self-healing schemes for the true end-to-end service protection.

We assume that STM based networks and ATM networks are coexisting at least ten years from now. Determining which self-healing schemes are needed to implement is a key issue to the network service providers and equipment vendors. It will guide current and future product planning. "One size" does not fit all to support varied customer requirements such as levels of fault coverage and restoration time performance(from hitless to several minutes). SONET rings have become a standard for survivable network infrastructure. Network providers are adding ATM equipments to embedded SONET networks. Therefore, survivability must be extended to new ATM services. Self-healing schems at the ATM layer are still in the early stage of development and the self-healing strategy tradeoff between SONET/SDH and ATM schemes remains to be further studied.

References

〔1〕 CCITT Recommendation G.803, "Architectures of Transport Networks Based on the synchronous Digital Hierarchy (SDH)," COM XVIII-R 106E, July 1992.

〔2〕 TA-NWT-1230 SONET Line Switching Ring Criteria, Issue 1, Bellcore, October 1991.

〔3〕 TR-TSY-496 SONET Add-Drop Multiplex Equipment(SONET ADM) Generic Criteria for Unidirectional, Dual-Fed, Path Protection Switched Self-Healing Ring Implementation, Bellcore Issue 2, September, 1991.

〔4〕 Grover,W.D. Venables, B.D.,et al,"Development and Performance Assessment of a Distributed Asynchronous Protocol for Real-Time Network Restoration", IEEE Journal on Selected Area in Communications, Vol. 9, No. 1, Jan. 1991, pp.112-125.

〔5〕 Kawamura, R.,et al,"Self-Healing ATM Networks Based on Virtual Path Concept", IEEE Journal on Selected Area in Communications, Vol. 12, No. 1, Jan. 1994, pp.120-127.

〔6〕 Noh,T.H.,et al,"Reconfiguration for Service and Self-Healing in ATM Networks Based on Virtual Paths", 12th ICCC, Vol. 2, August,1995, pp.525-530.

저 자 소 개

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