Network Reliability Council (NRC)

Reliability Issues - Changing Technologies Focus Group

Synchronous Optical Network/ Asynchronous Transfer Mode (SONET/ATM) Subteam Final Report

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Tom J. Ciaccia	AT&T Network Systems
Gary W. Ester	Alcatel Network Systems
Raghavan Kalkunte	Bellcore
Lee Leong	Fujitsu Network Switching
Chuck Norman	Sprint
Dave McDysan (Chair)	MCI Telecommunications
Steve Oliva	Sprint
Jay Shah	MCI Telecommunications
Benson Wang (Editor)	AT&T
Gene Wagner (Secretary)	Ameritech
Mike Zeug	Ameritech

TABLE OF CONTENTS

1. Executive Summary

The SONET/ATM subteam of the Changing Technologies Focus Group was chartered to assess the reliability impact of Synchronous Optical Network/Asynchronous Transfer Mode (SONET/ATM) technology on key services, for example, Plain Old Telephone Service (POTS) as identified in the Federal Communications Commission (FCC) Network Reliablity Council (NRC) issue statement (Appendix A).

All carriers and manufacturers that participated in the surveys were invited to also participate in the subteam's effort. Representatives from four carriers and four manufacturers actively participated in the effort. The team conducted its business through conference calls and electronic mail.

The SONET/ATM subteam developed a general questionnaire and a specific outage questionnaire. Because of funding limitations, only the generic questionaire was distributed and analyzed. Tutorials on SONET linear transmission systems and rings (Appendix E) , SONET DXC-based restoration (Appendix F) and ATM (Appendix G) were also developed as part of the final report.

Some key findings of the survey are summarized below:

- SONET comprises over 40% of the current transmission network deployment
- ATM will be used in providing key services in the next 4-6 years
- Most carriers (55%) do not consider a successful SONET switchover to be an outage
- Those carriers who track unsuccessful SONET ring switchovers report less than one outage per year

Based on the analysis of the survey results and research regarding the state of the industry, the team proposes the following recommendations:

- The current outage reporting requirements are adequate. However, detailed internal tracking of outage events is a recommended best practice.
- Committee T1X1 should update the reference SONET ring configuration to reflect actual implementations.
- Carriers should consider extension of failure mode tracking and analysis to the case of multiple failures.
- Industry standards bodies and fora should focus on standardization of ATM survivability.

In summary, SONET appears to be highly reliable, performing as designed. Carriers should continue to track internally SONET-related outages in the event that future investigations require this data. The widespread usage of ATM to provide various services will also likely occur within the next several years, so that more work needs to be done in standards and the industry to ensure that the end-to-end service levels are adequate.

2. Background

2.1 Charter/Introduction

The charter of the SONET/ATM subteam was to assess the reliability impact on key services by the introduction of SONET/ATM technology. The team defined key services to include the following:

- Plain Old Telephone Service (POTS)
- E-911
- Operator Services
- Common Channel Signaling (CCS)

The subteam scheduled conference calls at least once every two weeks to discuss and work on the study. The subteam held teleconferences once a week during the survey analysis, presentation development and final report generation. The subteam used electronic mail to distribute draft surveys, notes, draft presentations, survey results and final report drafts. Tom Ciaccia of AT&T provided an important service by deploying an Email exploder for the team.

The subteam worked towards consensus wherever possible. When disagreements occurred all opinions are reported. This report documents the presentation of the analysis of findings and recommendations presented to the NOREST II committee.

2.2 An Overview of SONET and ATM

This section provides a brief overview of SONET and ATM technology. More detailed overviews can be found in Appendices E (SONET Tutorial), F (SONET-Based DCS Restoration) and G (ATM Switching Tutorial) of this report.

2.2.1 SONET Technology

The Synchronous Optical Network (SONET) is a set of optical interface standards proposed by Bellcore to the ANSI T1 committees in 1984 for optical communications. Its original objective was to produce a common standard for all fiber-optic transmission equipment to achieve mid-span meet and network interoperability capabilities in a multiple-supplier environment.

A hierarchy of SONET rates and formats for each SONET Optical Carrier at Level N (OC-N) have been specified, where N is either 1, 3, 12, 24, 48, or 192. The transmission rate for any other signal level OC-N is simply at the N x 51.84 Mbps rate. SONET includes section, line and path overhead, and payload capacity, which is used to carry the actual information, such as DS3 and DS1 voice service, or ATM cells.

SONET network architectures include linear, ring or mesh configurations. A linear network is usually configured by two or more SONET terminals or add/drop multiplexers to provide point-to-point paths between two locations with line protection switching. A ring network is defined as

a set of SONET network elements with ring capabilities connecting with fibers to form a closed loop. Currently, the three commercially available SONET ring network types are: (1) two-fiber unidirectional path-switched ring (UPSR), (2) two-fiber bidirectional line-switched ring(2-f BLSR), and (3) four-fiber bidirectional line-switched ring (4-f BLSR). A mesh network is usually composed of a set of SONET cross connects to support multiple alternate routes for traffic restoration when a working route in the network is cut. All of the above SONET network architectures have been successfully and widely deployed currently in boththe United States and Canada.

The required protection switching times for the length of hits in both linear and ring networks are within 50 milliseconds for each single signal failure event, and within 100 milliseconds for second and successive ring multiple signal failure events. The traffic restoration times in a DCS mesh network are estimated as about several minutes for the centralized restoration approach, and several seconds, for the distributed restoration approach.

Wideband and broadband DCSs are considered intelligent Network Elements (NEs) in transport networks. They serve as a convenient way to groom traffic and provide network facility management functions to the present network, as well as to the evolving SONET structure.

2.2.2 ATM Technology
ATM is a broadband technology, aimed at integrating voice, data, video and multimedia services over a common transmission and switching infrastructure. ATM standards and specifications have been developed in both national and international standards bodies, and a wide variety of ATM products have been developed by suppliers. Originally envisioned as the technology of choice for future broadband telecommunications networks, ATM has also been embraced by the data communications industry in both local-and wide area network(LAN and WAN) applications. This has been driven by the increasing bandwidth demands of desktop applications such as computer aided design(CAD), transfer of large database files and various types of multi-media applications. It is expected that ATM will provide the combination of scaleable bandwidth on demand and low end-to-end delay that cannot be efficiently supported by today's network technology

ATM is a cell-based technology that uses fixed-length cells, 53 octets long. This contrasts with SONET technology where dedicated time division multiplexed (TDM) capacity is allocated, or packet based technology, where variable length packets of data are transmitted. The fixed cell length of ATM facilitates cost-effective implementations of very high-speed interfaces and large switching systems. Further, the fixed cell size allows multiple service categories supporting different qualities of service to be readily implemented; enabling the integration of voice, data and video services.

Each ATM cell has an address comprised of a path and channel component. ATM is inherently a connection-oriented, or circuit based protocol and supports either Permanent Virtual Circuits (PVCs), or Switched Virtual Circuits (SVCs), which are based upon a signaling protocol built up

from concepts developed in ISDN. Higher level protocols, called ATM Adaptation Layers (AALs) are used in ATM for supporting emulated circuits; real-time applications, such as voice and video; connection-oriented data services, such as frame relay and X.25; and connectionless data services, such as Switched Multimegabit Data Service (SMDS) and the Internet Protocol (IP).

A number of key user oriented services are either already implemented, or being defined for operation over ATM. These include LAN emulation, Frame Relay/ATM interworking, IP/ATM interworking, video over ATM, circuit emulation over ATM, and voice over ATM.

Alternate routing of Virtual Path Connections (VPCs) and Virtual Circuit Connections (VCCs) is an important means of increasing robustness in ATM networks. A list of alternate routes selected at the time of original call/connection for PVC and SVC services could be pre-established. When the direct route is not available, due for example to a facility failure, the ATM switch should examine the list of alternate routes, and find a route with the list of suitable alternate routes. VCCs and VPCs in ATM networks can have heterogeneous bandwidth and Quality of Service(QoS) requirements that must be taken into account by the route selection algorithms when establishing alternate routes.

ATM-level protection switching is under study in standards bodies and it is premature to specify requirements at this time. Presently, there are no contributions in the ATM Forum that discuss the issue of alternate routing for VPCs and VCCs. Some preliminary work related to protection switching, which involved possible uses of Virtual Path (VP) cross-connect capabilities added to a Digital Cross-Connect to enhance the survivability and robustness of the core transmission network resources, has been performed by Bellcore.

2.3 Recommendation and Best Practice Definition

The terms "recommendation" or "best practice" as used in this report are defined as follows: "recommendations" are those countermeasures (but not the only countermeasures) which go furthest in eliminating the root cause(s) of outages. None of the recommendations are construed to be mandatory.

Service providers and suppliers are strongly encouraged to study and assess the applicability of all countermeasures for implementation in their company products. It is understood that all countermeasures, including those designated as "highly recommended," may not be applied universally.

3. Team Membership

The SONET/ATM subteam members were as follows:

Tom J. Ciaccia	AT&T Network Systems
Gary W. Ester	Alcatel Network Systems
Raghavan Kalkunte	Bellcore

Lee Leong	Fujitsu Network Switching
Chuck Norman	Sprint
Dave McDysan (Chair)	MCI Telecommunications
Steve Oliva	Sprint
Jay Shah	MCI Telecommunications
Benson Wang (Editor)	AT&T
Gene Wagner (Secretary)	Ameritech
Mike Zeug	Ameritech

4. Data Collection and Analysis Methodology

4.1 Data Collection Methodology

Bellcore was the central point for requesting, collecting, compiling and aggregating data for all focus area teams. All data provided to Bellcore were protected under a non-disclosure agreement. The data were treated as proprietary information, with specific references to individual service providers or manufacturers removed during the aggregation process. Each focus area defined its own data needs.

The SONET/ATM subteam determined its primary information needs to be the following:

- Assess near-term SONET/ATM plans of manufacturers and carriers, as well as plans for the 1-3 year, 4-6 year and 7 plus year time frames
- Determine the extent and methods of SONET deployment
- Determine the extent of SONET-related outages
- Survey best practices and outage tracking methodologies

To gather the required information, the subteam proposed the distribution of a high-level SONET/ATM data request and a detailed outage questionnaire. Because of funding limitations, only the high-level data questionnaire could be distributed and analyzed by Bellcore. A detailed outage questionnaire was developed by the subteam, however, and is recommended for internal carrier use as part of a set of recommended best practices (See Appendix D).

Persons responsible for the manufacture or use of SONET/ATM networks were surveyed via the "SONET/ATM Data Request" (see Appendix B). The development and fielding of the questionnaire was a joint effort of Bellcore and the subteam, with the subteam providing guidance as to its content, and Bellcore providing expertise in questionnaire construction and distribution, and the aggregating of the results. The questionnaires were distributed to 60 companies representing a variety of industry segments, including interexchange carriers (ICs), local exchange carriers (LECs), cellular providers, cable providers, manufacturers, satellite providers, mobile satellite providers, and competitive access providers.

The data request consisted of two sections: the first section targeted SONET/ATM manufacturers, while the second section targeted service providers using SONET/ATM systems. Useful data were received from 8 manufacturers and 22 service providers. In addition several companies responded that the request was not applicable because they were neither a provider nor a user of SONET/ATM systems or equipment.

Bellcore aggregated the 30 responses from the manufacturers and service providers and worked with the subteam to develop the analysis shown in Section 5. Summary conclusions and recommendations were derived from the survey results through a series of conference calls and via Email dialogue. The sections that follow present the results of the SONET/ATM subteam's analysis.

4.2 Analysis Methodology

The team defined categories for SONET/ATM systems as follows for use in the survey:

- Non-SONET transmission systems
- Linear SONET transmission systems
- SONET ring systems
- ATM switching systems

The team chose the percentage of equivalent DS0 miles deployed by carriers covered by each technology as the metric to measure the extent of SONET and ATM deployment.

The team initially prepared a detailed survey, including a number of detailed outage questions shown in Appendix D. This outage survey was largely based upon the Digital Crossconnect System (DCS) from the June, FCC NRC 1993 Report to the Nation. The team added T1A1 outage categories in the detailed questionnaire. The team hypothesized that SONET would likely have fewer outages, but that the individual outages could be larger. The team intended to use the outage survey to review the adequacy of using equivalent blocked calls as the reporting measure.

A key consideration of the survey was to determine whether SONET outages were a significant problem. The sensitivity to SONET switchover times, and whether carriers considered switchovers as an outage, were issues the survey targeted.

The subteam decided to limit the scope of the effort to key services (e.g., POTS) over SONET/ATM as defined in the FCC NRC issue statement. The survey, however, only asked about "key services", and did not give a definition. Therefore, the respondents may have considered different services as key. For example, the team excluded "data" as a key service, however; it is unknown how the respondents interpreted this question.

The subteam was also concerned that the lack of physical diversity could lead to critical failure modes and as such could impact reliability. The subteam interpreted the lack of fiber-ring diversity as a folded ring (i.e., a portion of the fiber ring is routed in single conduit). However,

respondents may have considered the lack of fiber-ring diversity as not having Dual Ring Interworking (DRI) with interconnection at diverse points. Such interworking is designed to protect against the loss of a node, or ring interconnections.

5. Study Results

Bellcore sent the survey to 60 companies. Thirty responses were received. The categories of the respondents are shown in Figure 5.1.
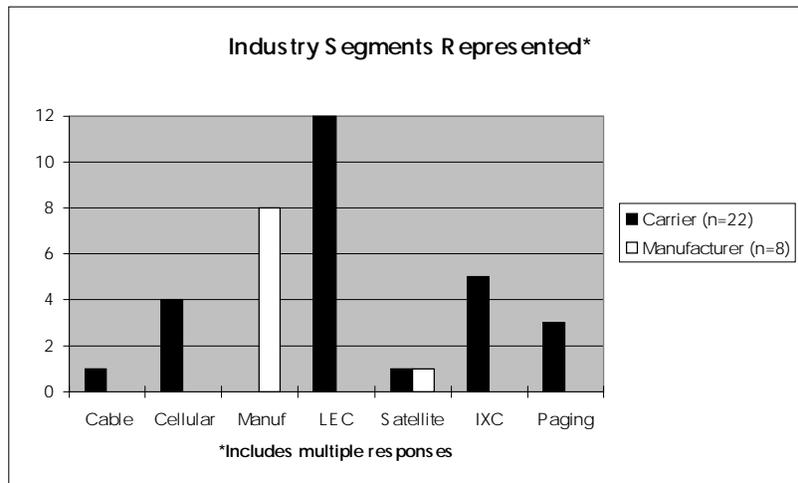
Figure 5.1. Industry Segments Represented

Mark Williamson of Bellcore analyzed the responses to the survey so that information about individual respondents could not be determined. The survey is attached in Appendix B.

5.1 Summary of Manufacturer Response Analysis

There were 30 responses to the survey, 22 from carriers, and 8 from manufactures, as shown in Figure 5.1. Each manufacturer responded to nine questions, specifically focused on SONET and ATM products (see Appendix B). The results of these questions are shown in Figures 5.2 through 5.10.

Figure 5.2 shows the breakdown of the products manufactured by the 8 respondents, 5 offer linear SONET systems, 4 offer SONET ring systems, 4 offer SONET cross-connects, and 5 offer ATM switches, cross-connects or multiplexers.

10

Products Manufactured

[A stacked bar chart titled "Products Manufactured" showing Responses (y-axis 0 to 8) for four product categories. The chart has a legend with NO (white) and YES (black). Values: LINEAR APS SONET = 5 YES, RING SONET = 4 YES, SONET CCs = 4 YES, ATM SWITCHES, CCs, MUXs = 5 YES.]

Figure 5.2 - Products Manufactured

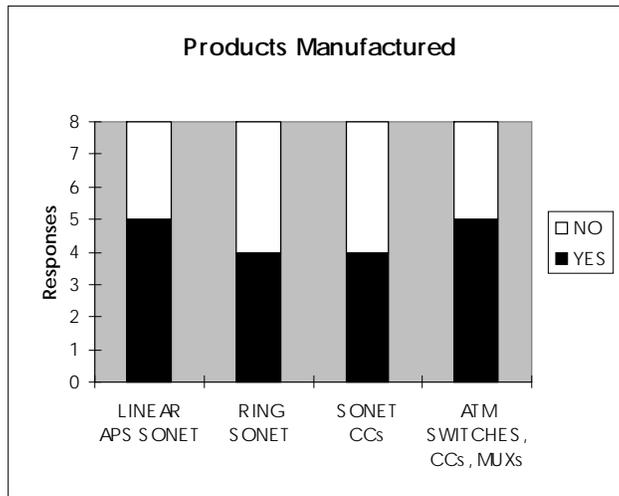Question 2 expands on question 1, and asks if the company develops or plans to develop SONET and/or ATM products. The responses are shown in Figure 5.3. The plans for a future offering of the same products are listed, however, there is a discrepancy in the responses. Four manufacturers said they currently offer linear SONET systems, whereas in question 1, 5 manufacturers said they were offering linear SONET systems. One manufacturer in each of the, linear SONET, SONET ring, and SONET cross-connects categories, planned to offer these systems in the future. All eight manufacturers have plans to offer ATM switches, cross-connects, or multiplexers in the future.

Plans To Develop Products with SONET/ATM Interfaces

[A stacked bar chart titled "Plans To Develop Products with SONET/ATM Interfaces" showing Responses (y-axis 0 to 8) for four product categories. Legend: NO PLAN TO DEVELOP (white), PLAN TO DEVELOP (gray), CURRENTLY DEVELOP (black). Values approximately: LINEAR APS SONET = 4 currently, 1 plan; RING SONET = 4 currently, 1 plan; SONET CCs = 4 currently, 1 plan; ATM SWITCHES, CCs, MUXs = 5 currently, 3 plan.]
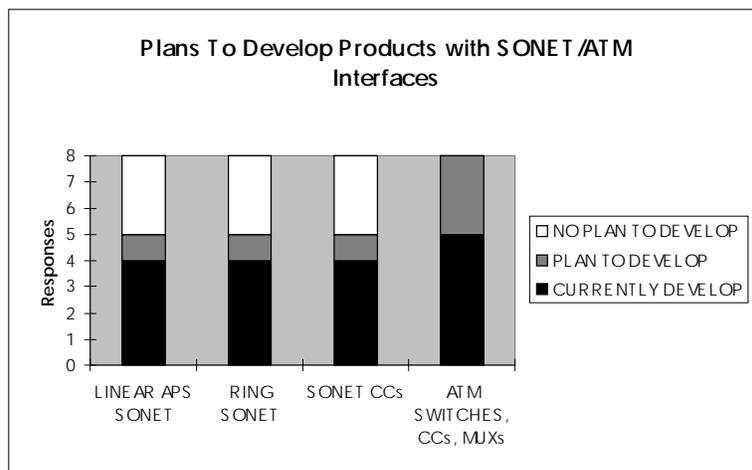
Figure 5.3 - Plans for Future SONET and ATM Products

Question 3 asked for projected revenue mix between the various products; the responses are shown in Figure 5.4. SONET products—linear, ring, and cross-connects—represent a constant

percentage of the expected revenue. Non-SONET products will decline from 45% to 20% of projected revenue, and ATM products—switches, cross-connects, and multiplexers—will increase from 4% today to 40% in seven years.
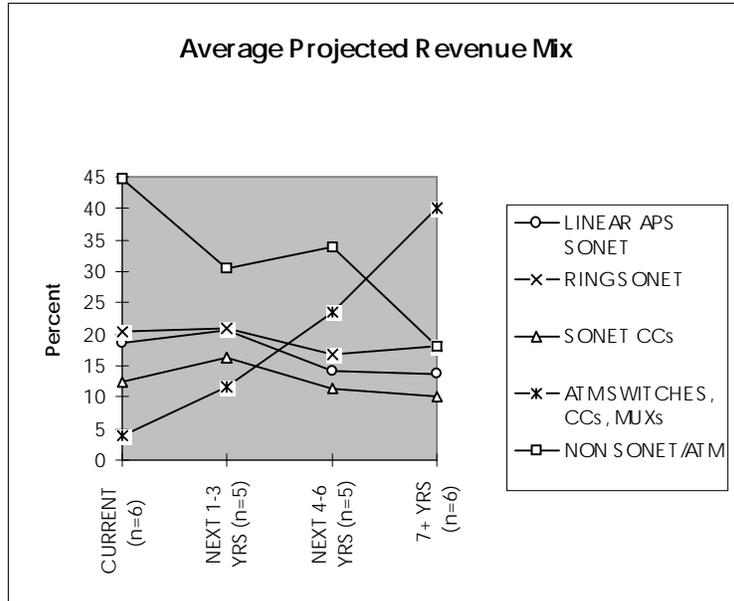
Average Projected Revenue Mix

Figure 5.4 - Projected Revenue Mix from SONET and ATM Products

Question 4 deals with SONET interface rates offered; the responses are shown in Figure 5.5.

SONET Interface Rates

Figure 5.5 - SONET Interface Rates Offered

Most manufacturers responded that their SONET products support some form of restoration (see Figure 5.6).
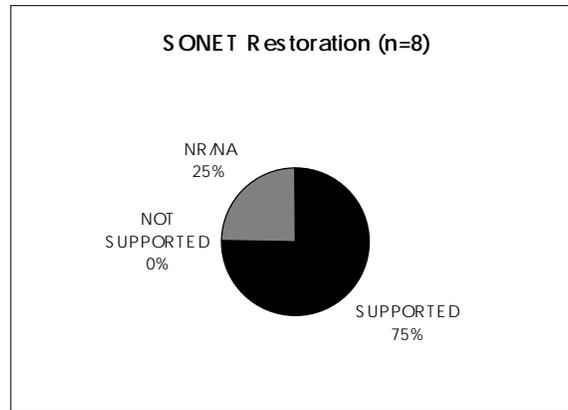
Figure 5.6 - SONET Products That Support Restoration

As for the ATM interface rates and cell rates, the responses indicated that more manufacturers' ATM products support DS-1/T-1/Asynchronous digital, DS-3/T-3/Asynchronous digital, STS-3/OC-3 SONET, and SDH interfaces than other interfaces such as STS-1/OC-1 SONET, STS-12/OC-12 SONET, or STS-48/OC-48 SONET (see Figures 5.7 and 5.8).
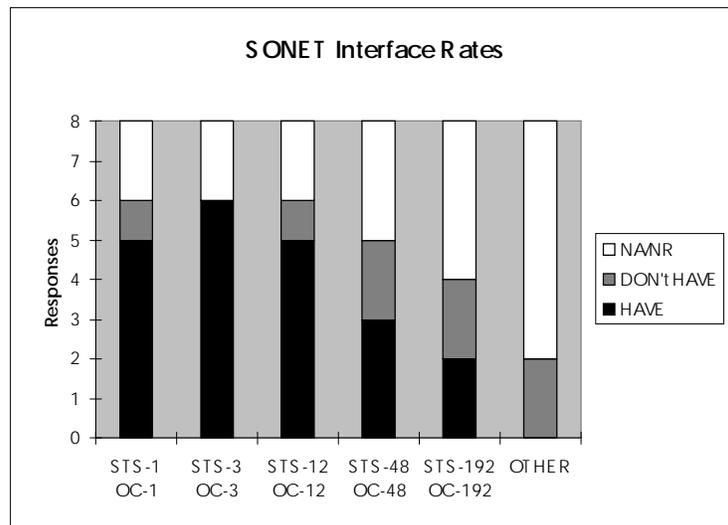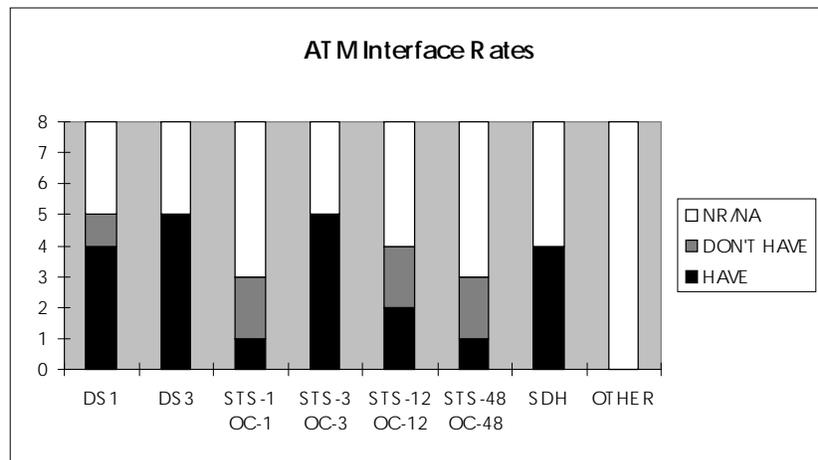

Figure 5.7 - ATM Interface Rates Offered
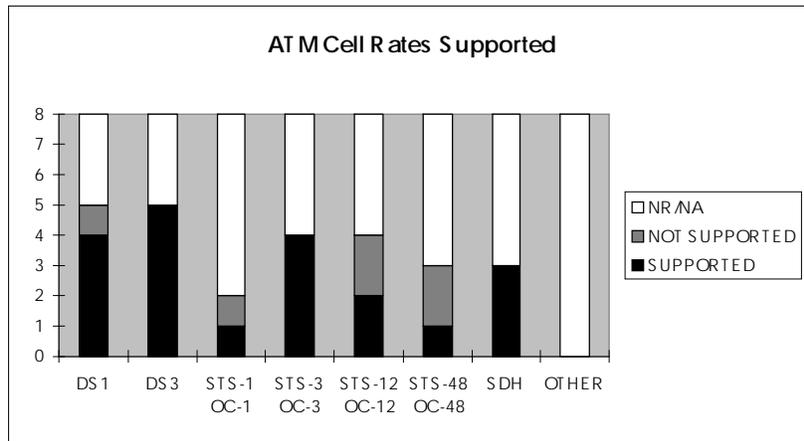
Figure 5.8 - ATM Cell Rates Offered

Most manufacturers responded that their ATM products support some form of restoration (see Figure 5.9).
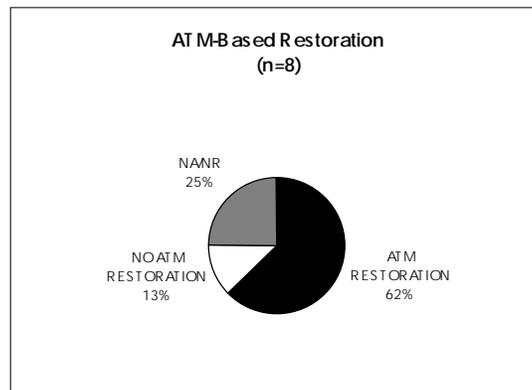
Figure 5.9 - ATM Products That Support Restoration

Manufacturers expect that with their SONET/ATM products mean time between failures (MTBF) will increase and mean time to repair (MTTR) will decrease (see Figure 5.10). The interpretation of these responses is that the manufacturers expect overall availability to increase with their SONET/ATM products.
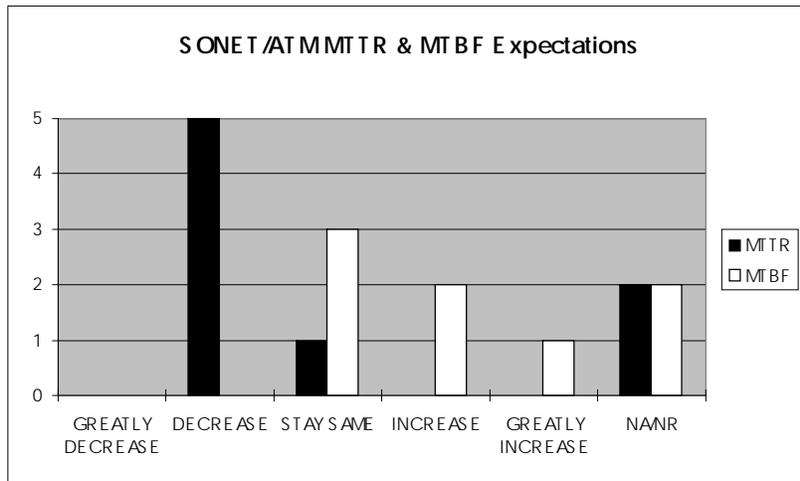
Figure 5.10 - Expected Reliability/Availability Improvements

5.2 Summary of Carrier Response Analysis

As shown in Figure 5.11, the carriers reported approximately 35,000 SONET network elements, with OC-3 units being the most numerous.
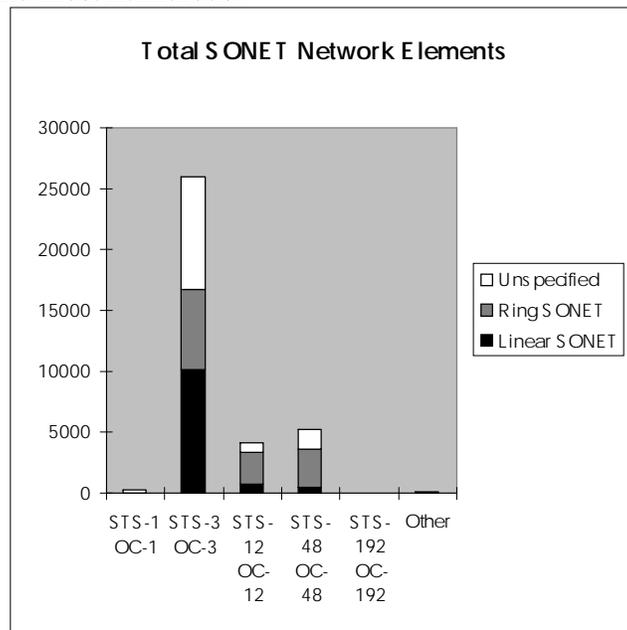
Figure 5.11 - Total Carrier SONET Network Elements)

As shown in Figure 5.12, most carriers utilize linear SONET and SONET ring configurations to provide key services today[*]. Most carriers plan to use SONET/ATM technologies within three years.

Percent DS0 Equivalent Miles
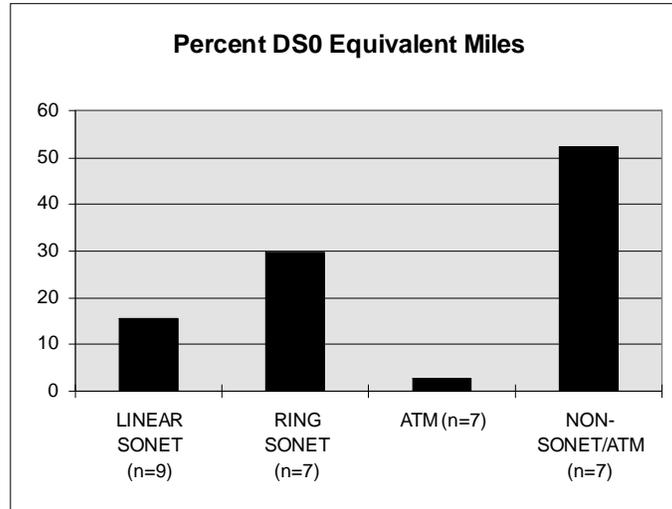
Figure 5.12 - Carriers' Percent DS0 Equivalent Miles

Most facilities today are traditional (i.e., non-SONET/ATM); however, linear and ring SONET together represent a significant fraction of facilities. ATM does not represent a significant portion of today's network facilities.

The majority of non-SONET/ATM facilities in use today have physical diversity. However, as shown in Figure 5.13, most SONET facilities do not have physical diversity. The reported SONET physical diversity of approximately 25% may be lower than desirable, depending on the architecture of the overall system. Two carriers reported ATM diversity, both at 100%.

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[*] "Key services" were not defined in the survey. The subteam does not believe that this significantly detracts from or unduly biases the survey results. Any exceptions are noted.
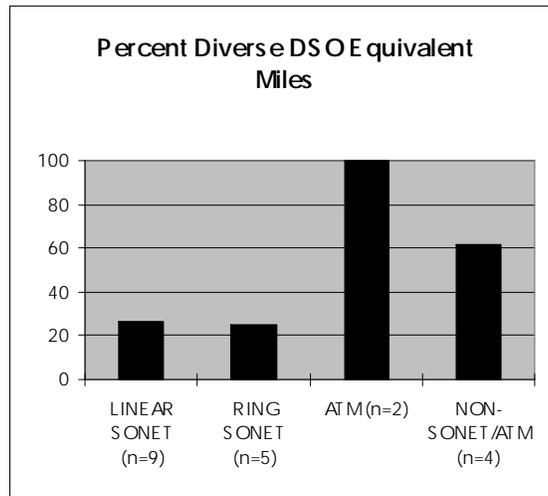
Figure 5.13 - Carriers' Percent Diverse DS0 Equivalent Miles

For both SONET and ATM, about half the carriers track outages greater than approximately 60 milliseconds (ms). As shown in Figure 5.14, the majority of carriers do not consider a 60-ms SONET ring switchover an outage.
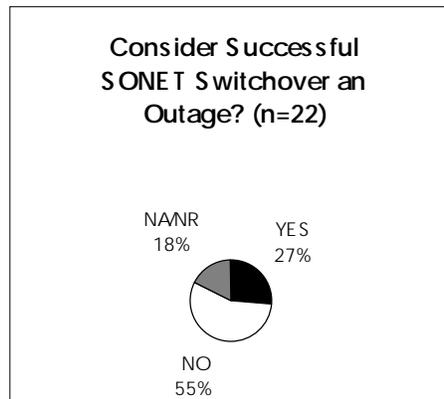
Figure 5.14 - SONET Switchovers as an Outage

<Recommendation 1>

Carriers should establish internal SONET and ATM data collection processes that collect outage-specific data, root cause(s) of the outage, and recommendations for prevention.

An example of a detailed outage reporting form for SONET is shown in Appendix D. If outage reports indicate that there is an endemic problem with SONET or ATM outages, then the NRC steering committee may request this data in the future for subsequent survey.

In the past, the focus has been on major failure events and not on the overall percentage of time that service is available. Indeed, major failures in carrier networks make headlines, whereas a ten percent reduction in availability may go unnoticed. Also, if the time to repair is minimal, even large outages may go unnoticed. As the line rates increase, the cross section of affected equivalent calls will increase. Although systems will be designed to survive one or more failures, the impact of multiple failures, if they occur, will likely make headlines.

<Recommendation 2>

> Carriers should consider developing pre-plans and the associated training for multiple failures and the large outages that could result. This planning and training development should include multiple failure mode tracking and root cause analysis analogous to that recommended for single failures.

Whether they consider it an outage or not, only 6 of 18 carriers (33%) actually track successful switchovers, and none provided information on the number of successful switchovers. As shown in Figure 5.15, approximately 60% of carriers track unsuccesful SONET ring switchovers.

Track Unsuccessful SONET Switchovers?
(n=16)

NO 38%

YES 62%
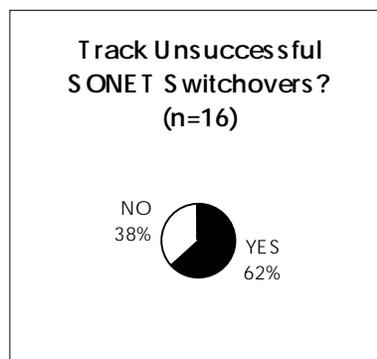
Figure 5.15 - Tracking of Unsuccessful SONET Switchovers

Seven carriers reported their unsuccessful switchover rate: three had none, three had one unsuccessful switchover and one averages 2.5 unsuccessful switchovers per year.

The current standard developed by T1X1.5, T1.105.01-1994, limits shared protection rings to 16 stations, and 1200 km circumference to achieve 60 ms switching time (10 ms detect + 50 ms switch). The team's concern is that the current standards may need enhancement to increase the number of stations and the ring circumference. Interoperation in a multi-vendor environment is the reason that contributions to extend these limits should be brought forward by manufacturers and/or carriers.

<Recommendation 3>

> Committee T1X1 should update the reference to SONET ring configurations to reflect actual implementations.

Carriers are divided on whether they plan to use SONET cross-connects for restoration. Of the carriers using SONET cross connects, all seven indicated they plan to use them for restoration (Figure 5.16).
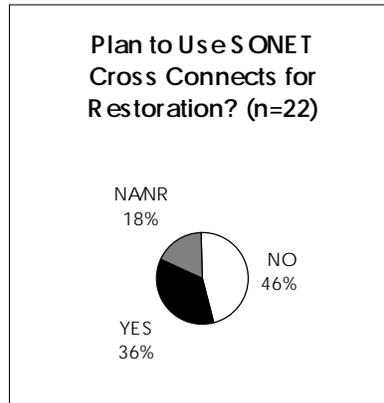
Figure 5.16 - Plans to Use SONET Cross-Connects for Restoration

The carriers reported 88 ATM switching nodes in use (Figure 5.17), with the majority of switches having 10 Gbps or more of total throughput.
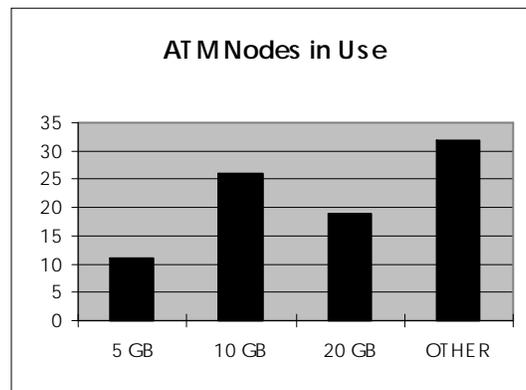
Figure 5.17 - ATM Switching Nodes in Use

Carrier ATM survivability plans consisted of either physical port survivability or logical path protection switching, both, or one or both with other plans. Only 5% responded that they had no survivability plan.

Survivability techniques for ATM are not standardized. The significant carrier plans to provide key services over ATM as identified from the survey report indicate that more focus should be placed on developing ATM survivability standards. The team notes that both T1S1.5 and ITU Study Group 13 have ATM survivability issues slated for consideration in 1996.

<Recommendation 4>

In light of the significant carrier plans to provide key services over ATM, the ATM Forum and Committee T1 are encouraged to develop survivability standards for ATM that focus on resilient interconnection and a multi-vendor environment. The industry should work through Committee T1 and the Network Operations Forum.

The majority of carriers have special procedures and/or standards to ensure reliability for SONET and ATM (Figures 5.18 and 5.19, respectively).
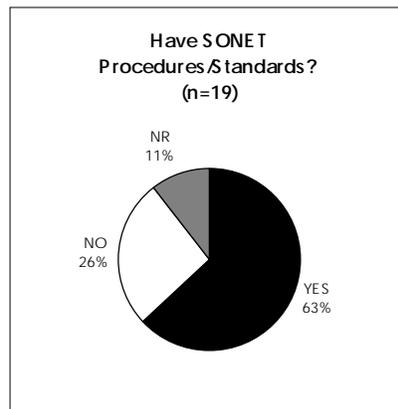
Figure 5.18 - Special Carrier Procedures/Standards for SONET Reliability
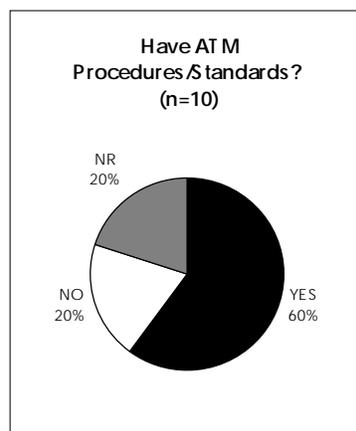
Figure 5.19 - Special Carrier Procedures/Standards for ATM Reliability

Question 12 of the carrier section of the survey (Appendix B) asked respondents to identify special procedures and/or standards used to ensure the reliability of their SONET and ATM networks. The following list, which illustrates the range of special procedures and/or standards used by carriers for SONET, tabulates responses to this question:

- **Architecture**
  Rings
  Redundant hardware
  Diverse paths
  Uptime requirements
- **Standards/Specifications**
- **Operating Methods**
  Periodic vendor/operations meetings
  Acceptance, test and turn-up procedures
  Electro-static discharge
- **On-going Quality Assurance**
  Alarm monitoring and performance measurements via OSS
  Maintenance program including maintenance window
  Bellcore Reliability Review Forum
  Root cause analysis

The majority of carriers have special procedures for ATM (Figure 5.10). Twelve specific items were identified addressing the following:

- **Architecture**
  Redundant hardware
  Diversity (intra- and inter-office)
  Based on high survivability SONET network
- **Standards/Specifications**[**]
  Bellcore
  ATM Forum
- **Operating Methods**
  Dedicated technicians
  Highly trained 24-hour technical support
  Constant surveillance
  Controlled/NEBS environment

In addition, one carrier reported that procedures for ATM reliability were under development.

Question 13 of the carrier section of the survey (Appendix B) solicited recommendations to be followed by the industry for Best Practices involved with providing and interconnecting SONET and ATM networks carrying key services. The following list tabulates the responses received to this question:

[**] Although respondents mentioned only Bellcore and the ATM Forum as sources of standards/specifications, the team recognizes related standards activities in bodies such as Committee T1 and the ITU.

- **Architecture**
  Rings
  Diversity (electrical and physical)
  Integrated SONET/ATM[***]
  Separate SONET/ATM switching[***]
  Recovery requirements
  Availability requirements
- **Standards/Specifications[**]**
  Bellcore
  ATM Forum
  Issues requiring standards/specifications
     Remote inventory management
     Performance measurement
     Network/node health
- **Interoperability**
  Common interfaces
  Network
  Vendor
  Operations Support Systems (OSS)

<Recommendation 5>

Emphasis should be placed on personnel training, centralized operations support and mechanisms to identify, and automatically correct network abnormalities, documentation and contingency planning. As SONET continues to be increasingly deployed in carrier networks, these processes and mechanisms should become part of the standard operating procedure. Also, as ATM begins deployment, carriers should not not overlook the basics: developing training and implementing sound operational procedures.

[***] Contrary views were expressed as to whether SONET & ATM should be integrated or separate.

6. Summary of Conclusions

This section presents the key conclusions and "best practices" recommendations produced by the subteam.

6.1 Collection of Additional Outage Data by Carriers for Internal Tracking Purposes

<Recommendation 1>
Carriers should establish SONET and ATM data collection processes that collect outage-specific data, root cause(s) of the outage, and recommendations for prevention.

<Recommendation 2>
Carriers should consider developing pre-plans and the associated training for multiple failures and the large outages that could result. This planning and training development should include multiple failure mode tracking and root cause analysis analogous to that recommended for single failures.

6.2 Additional Standards Work Recommended

<Recommendation 3>
Committee T1X1 should update the reference to SONET ring configuration to reflect actual implementations.

<Recommendation 4>
In light of the significant carrier plans to provide key services over ATM, the ATM Forum and Committee T1 are encouraged to develop survivability standards for ATM that focus on resilient interconnection and a multi-vendor environment. The industry should work through Committee T1and the Network Operations Forum.

6.2 Operations-oriented Recommendations

<Recommendation 5>
Emphasis should be placed on personnel training, centralized operations support and mechanisms to identify, and automatically correct network abnormalities, documentation and contingency planning. As SONET continues to be increasingly deployed in carrier networks, these processes and mechanisms should become part of the standard operating procedure. Also, as ATM begins deployment, carriers should not not overlook the basics: developing training and implementing sound operational procedures.

7. Metrics

The subteam determined that the current reporting measure of the equivalent number of blocked calls was still adequate. As other services, such as switched video, become regarded as "key" other measures may require development.

Therefore, the team does not recommend any additional metrics for outage reporting or tracking.

8. Path Forward

The subteam wanted to minimize any additional reporting burdens, in the absence of evidence of any problem with SONET. The team discussed, but did not recommend, that funding for the distribution and analysis of the detailed outage of survey of Appendix D be considered. In particular, the team believed that SONET was reasonably mature, subject to much analysis and modeling, and apparently performing acceptably. SONET should increase network reliability and not cause degradation. Additional reporting, in the absence of evidence to indicate a need, is not recommended. Regarding ATM, deployment is probably so limited that recommendations on any data collected in the next year or two might not be valid.

8.1 Adequacy of FCC Reporting Requirements

The mandatory reporting requirements are specified in FCC Rules Section 63.100, Notification of Service Outage, (and repeated in *Network Reliability: A Report to the Nation*, June 1993, Chart 12 of Section I, page 14). The following list of items are required to be reported for a major outage:

1. Carrier Name, Contact Telephone Number
2. Date and Time of Incident
3. Geographical Area Affected
4. Number of Customers Affected
5. Type of Services Affected
6. Duration of Incident
7. Number of Blocked Calls
8. Cause of Incident
   -Name and Type of Equipment Involved
9. Methods Used to Restore Service
10. Steps to Prevent Recurrence

There is no standard form, but the FCC expects carriers to report the type of equipment and manufacturer in an outage report as indicated above.

The subteam determined the current reporting measure of the equivalent number of blocked calls to still be adequate. As other services, such as switched video, become key other measures may require development.

The subteam recommends that carriers adopt the practice of collecting the data shown in Appendix D for at least the FCC-reportable outages for internal tracking purposes only. If outage reports indicate that there is an endemic problem with SONET or ATM outages, then the NRSC steering committee may request this data in the future

8.2 Better Definition of Key Services

The subteam believes that a SONET/ATM reliability issue statement should better define what is meant by key services. For example, the current issue statement implicitly defined key services via a parenthetical example (e.g., POTS). Within the subteam there was not a consensus regarding the meaning of key services. The subteam believes that this uncertainty in definition may have also existed with those responding to the questionnaire.

9. Acknowledgements

The team thanks Ken Young for his chairmanship of the Changing Technologies focus group and for his collection of tutorial information from Bellcore. The team thanks Tsang-sung Chang of Bellcore for providing the SONET tutorial material in Appendix E. The team also thanks the NOREST steering committee for its helpful review and comments on the presentation in November.

10. Appendices

Appendix A - Issue Statement

Issue Title: Reliability Concerns Arising Out of Changing Technologies   **Author:** Gary Handler

Bellcore

Problem Statement/Issue to be Addressed

The national Public Switched Network (PSN) which is truly a network of networks, has the deserved reputation of providing its users highly reliable, survivable and secure end-to-end services. The FCC and its Network Reliability Council (NRC) want to ensure that this remains the standard mode of operation in spite of a dramatic increase in the number of new technologies being deployed, the implementation of advanced new services offered to the public, and the emergence of a proliferation of new service providers. In specific, the NRC will study a) the reliability aspects of the provision of key services over new network facilities, (i.e., broadband hybrid fiber/coaxial cable distribution, SONET and ATM, wireless, and satellite), and b) reliability concerns arising out of new technology providing expanded services over new or traditional facilities, i.e., Advanced Intelligent Network (AIN) capabilities. The emphasis of this Focus Team should be on new technology that will be implemented in the public network within the next three years.

Areas of Concern and Problem Quantification

The following are the main areas of concern:

1. **Reliability Aspects of Provision of Key Services Over New Network Facilities**
    a) *Broadband Networks* - One concern about new network technologies is how the reliability of services such as plain old telephone service provided over new broadband networks will compare with that of the same service provided over existing wireline technology. These new systems should be modeled and analyzed for potential reliability risks and possible reliability improvement techniques. Implementation "Best Practices" should be developed and a plan for their dissemination and implementation should be derived. Two specific areas should be addressed:
        i) *Hybrid Fiber/Coaxial Cable Distribution Systems* - This technology is expected to be providing telephone service shortly. The reliability issues with this technology need to be defined and addressed.
        ii) *SONET Facilities and ATM Technology* - SONET transport and ATM technology are rapidly progressing and will be providing new broadband services as well as existing narrowband services over common facilities. The reliability issues with these technologies need to be defined and addressed.

26

b) *Wireless Network (Cellular and PCS)* - Another example of a concern about new technologies is the role and reliability of cellular facilities in connection with line-based networks. This issue was discussed by the NRC at its September 30, 1992 meeting and in the document *Network Reliability: A Report to the Nation.* The reliability of the telecommunications services provided over a combination of new technologies has to be reviewed. Customers who rely on cellular technology need service providers to have and follow established "best practices." These do not now exist. Best practices for Personal Communications Services (PCS) and Networks should also be considered in this study.

c) *Satellite Networks* - Another area of reliability concern is the provision of telephone services over new satellite technology networks such as low earth orbiting satellites. The reliability issues with this technology should also be defined and addressed.

2. **Reliability Concerns Arising Out of New Technology Providing Expanded Services over New or Traditional Facilities, i.e., Advanced Intelligent Network (AIN) Capabilities** - Concerns have also been raised regarding the interoperability and reliability of multiple advanced intelligent services with their inherently independently developed software management and control. As John Clendenin stated at the July 6, 1994 NRC meeting "this is not the kind of problem that could be solved (once) and laid aside". However, to provide a near term objective from which a model or process might be developed, it is suggested that the team focus on the interoperability and reliability concerns in the development of Advanced Intelligent Network Services.

Description of Proposed Work

The team working this issue should consider the following total quality process to identify reliability concerns arising out of changing technologies, quantify network vulnerabilities, identify the major reliability issues and propose problem solutions.

1. Identify the new technologies being introduced into the network.

2. Collect appropriate data from all available industry sources to determine and/or confirm areas/technologies of greatest criticality and risk, and those with the greatest potential for network reliability improvement potential. (Work with the ATIS Network Reliability Steering Committee (NRSC) and its Network Reliability Performance Committee to coordinate data collection activities).

3. Collect data from the industry concerning the reliability of new technologies if already deployed. (Work with the ATIS Network Reliability Steering Committee (NRSC) and its Network Reliability Performance Committee to coordinate data collection activities)

4. Perform sufficient analysis of the data to determine the root cause(s) of the problem(s).

5. From the root cause analysis determine an appropriate action plan to reduce/eliminate the possibility or severity of failures in high risk areas. Also consider ways that recovery procedures may be implemented more quickly or efficiently.

6. Determine industry "best practices" for dealing with the root cause analysis findings and share this information with industry participants as soon as possible. Deployment should consider cost/benefit tradeoffs of "best practices."

7. Develop a timeline and metrics to measure the effectiveness of the team's recommendations.

8. Consider the following tactics/ideas offered by the Steering Team as potential means to supplement the total quality process and address the findings of the root cause analysis. These represent ideas from the Steering Team that we want to share.

    A. **New Technology Reliability Template** - Design a generic template that serves as a reliability screen for assessing the reliability of new network technologies. This could be used as a process for the rapid and reliable evolution of the telecommunications networks.

    B. **Provision of Key Services Over New Network Facilities**

1.   **Broadband Networks (Hybrid Fiber/Coaxial Cable Distribution and SONET Facilities & ATM Technology), Wireless Networks (Cellular & PCS), and Satellite Networks.**

        a) For each technology, determine the scope of the reliability study. Develop a bounded definition of the reliability problem; for example, the provision of basic telecommunications over a new broadband hybrid fiber/coaxial cable distribution network.

        b) Construct an order of magnitude (major failure modes and vulnerabilities) reliability model of a reference system for each technology.

        c) Collect available reliability data (e.g. current coaxial cable systems network outage & failure data, current cellular network outage and failure data, current SONET network outage and failure data and ATM switch reliability), concerns and "best practices" associated with each technology.

        d) Analyze data to quantify reliability and determine the most significant problem areas, and the areas with the greatest risks.

        e) Determine applicability of current "best practices" to the new technology and identify any additional "best practices" that describe quality as part of the introduction of new technologies (i.e., "best practices" applicable to hybrid fiber/coaxial cable networks, cellular networks, and SONET networks).

        f) Recommend implementation strategies for "best practices" and on-going process information for insuring continued quality.

2. Advanced Intelligent Network (AIN) Capabilities

      g) Determine the reliability issues associated with AIN services (e.g., management of many different versions of software).

      h) Identify efforts taken to date to address AIN reliability issues and to ensure AIN service reliability. Identify existing "best practices."

      i) Identify potential reliability "holes" or problem areas and recommend solutions.

      j) Identify the role that the IITP process might play as part of an implementation strategy for interoperability control and as a reliability qualification process for new AIN platforms, services and software. (Coordinate potential overlapping interconnection issues with the Network Interconnection Focus Team)

Existing Work Efforts

There are several work efforts that have addressed or are addressing some of these issues. The Fiber Cable Focus Team recommendations in the *Network Reliability: A Report to the Nation*, *the Telecommunication Industry Benchmark Committee (TIBC) Report*, Draft Congressional Bills S2101 and HR4394 on one-call legislation, and the ATIS/NRSC Annual Report provide significant data from which to begin to address the Provision of Key Services Over New Network Facilities issue. The ATIS Working Group on Network Survivability Performance, T1A1.2 and the News Release, DA-1343, requesting comments on Joint Petition for Rulemaking on Cable Television Wiring, RM No. 8380, November 15, 1993 provide background on the cellular and coax cable concerns. The Switching Systems (focus on software) Focus Team Recommendations in the *Network Reliability: A Report to the Nation* as well as ATIS/NOF/IITP charter and test plans give good background material for addressing the services and software concerns.

Recommended Team Leader

Ken Young - Bellcore

Appendix B - Data Request Questionnaire

John D. Healy
Director, Network
Integrity and Reliability

Bellcore
Bell Communications Research

June 16, 1995

**NRC Changing Technology
SONET/ATM Subteam Data Request**

Single Points of Contact for NRC Data Collection:

The Federal Communications Commission (FCC) has chartered the Network Reliability Council (NRC) to address a number of significant issues concerning maintaining and improving network reliability. These issues include, among other things, the impact of reliability concerns arising out of changing technologies.

To carry out its charter, the NRC has formed five focus groups. Each group will address an FCC identified issue:

Focus Group 1	Network Reliability Performance
Focus Group 2	Increased Interconnection
Focus Group 3	Changing Technologies
Focus Group 4	Essential Communications During Emergencies
Focus Group 5	Telecommuting as Back-Up in Disasters

You have already received data requests from many of the focus groups. Attached is the **LAST** data request. It is for the SONET/ATM Subteam of Focus Group 3 (NRC Changing Technologies Focus Group). There is only one part to this data request. The data request asks for general information on SONET/ATM deployment and reliability. The information you provide will be aggregated for use by the AIN Subteam of the Changing Technology Focus Group on an industry basis and not by company.

Your personal support of this data collection effort is essential for an effective accomplishment of the mission of the NRC. Please return the completed questionnaire within 21 days (i.e., by September 6, 1995) to:

> John Healy
> Bellcore, Room 2X-227
> 331 Newman Springs Road
> Red Bank, NJ 07701
> Tel: 908-758-3065
> Fax: 908-758-4502

If you have any questions, please call either John Healy at 908-758-3065 or Mark Williamson at 908-758-5184.

Thank you very much in advance for your cooperation.

John Healy

Attachment
Data Request

Copy to
Gary Handler
Clint Hamilton
Chao-Ming Liu
Mark Williamson
Ken Young

NRC FOCUS GROUP 3: Changing Technologies
SONET/ATM Data Request

Company Name:_____

Contact Name:_____ Telephone:_____

Your industry segment(s). Please check all that apply:

❏Cable Services   ❏Local Exchange Services   ❏Interexchange Services

❏Cellular Services   ❏Satellite Services   ❏Paging Services

❏Manufacturer   ❏Others:_____

Instructions: Please answer the manufacturer questions, the carrier questions, or both, as appropriate.

Manufacturer Questions:

1. Please indicate whether your company manufactures the following products:

Linear (APS) SONET Transmission Systems	❏ Yes ❏ No
Ring SONET Transmission Systems	❏ Yes ❏ No
SONET Cross Connects	❏ Yes ❏ No
ATM Switches or ATM Cross Connects or ATM MUXs	❏ Yes ❏ No

2. Do you develop or plan to develop products with SONET and/or ATM interfaces? (See Questions 4 and 6)

	Currently Develop These Products	Plan to Develop These Products	Do Not Plan to Develop These Products
Linear (APS) SONET Transmission Systems	❏	❏	❏
Ring SONET Transmission Systems	❏	❏	❏
SONET Cross Connects	❏	❏	❏
ATM Switches or ATM Cross Connects or ATM MUXs	❏	❏	❏

3. What is or will be the approximate percentage mix of the annual revenue from your transmission products? (The percentages in each column should add up to 100%)

	Now	Next 1-3 Years	Next 4-6 Years	Over 7 years
Linear (APS) SONET Transmission Systems				
Ring SONET Transmission Systems				
SONET Cross Connects				
ATM Switches or ATM Cross Connects or ATM MUXs				
Non SONET/ATM Transmission Products				

4. At what rates do the SONET interfaces operate?

	Operates at this Rate	Total Number of Interfaces or Ports Shipped To Date in the US	Supports Linear SONET Systems	Cell Rate(s) Supported
STS-1/OC-1	❏ Yes ❏ No		❏ Yes ❏ No	
STS-3/OC-3	❏ Yes ❏ No		❏ Yes ❏ No	
STS-12/OC-12	❏ Yes ❏ No		❏ Yes ❏ No	
STS-48/OC-48	❏ Yes ❏ No		❏ Yes ❏ No	
STS-192/OC-192	❏ Yes ❏ No		❏ Yes ❏ No	
OTHER_____	❏ Yes ❏ No		❏ Yes ❏ No	

5. Do your products support some form of restoration?   ❏ Yes   ❏ No
   If yes, please explain. (Use additional pages as necessary)

_____

6. At what rates and format do the ATM interfaces operate?

	Operates at this Rate	Total Number of Interfaces or Ports Shipped To Date in the US	Supports this Cell Rate
DS-1/T-1/ ASYNCHRONOUS Digital Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
DS-3/T-3/ASYNCHRONOUS Digital Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
STS-1/OC-1 SONET Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
STS-3/OC-3 SONET Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
STS-12/OC-12 SONET Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
STS-48/OC-48 SONET Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
SDH Hierarchy	❏ Yes ❏ No		❏ Yes ❏ No
OTHER_____	❏ Yes ❏ No		❏ Yes ❏ No

7. Do your products support some form of ATM based restoration?

❏ Yes   ❏ No

   If yes, please explain:

_____

8. Do you expect the Mean Time Between Failures (MTBF) to change for your SONET/ATM products as compared to similar Pleisiosynchronous Digital Hierarchy (non SONET/ATM) products?

❏ Greatly Decrease ❏ Decrease ❏ Stay Same ❏ Increase ❏ Greatly Increase

Please explain your response:

_____

9. Do you expect the Mean Time to Repair (MTTR) to change for your SONET/ATM products as compared to similar Pleisiosynchronous Digital Hierarchy (non SONET/ATM) products?

❏ Greatly Decrease ❏ Decrease ❏ Stay Same ❏ Increase ❏ Greatly Increase

Please explain your response:

_____

Carrier Questions:

1. Describe the population of SONET Network Elements in your network.

	Linear (APS) or Ring	Have Systems Operating at This Rate	Number of Terminals/ADMs
STS-1/OC-1	Linear (APS)	❏ Yes ❏ No	
STS-3/OC-3	Linear (APS)	❏ Yes ❏ No	
STS-12/OC-12	Linear (APS)	❏ Yes ❏ No	
STS-48/OC-48	Linear (APS)	❏ Yes ❏ No	
STS-192/OC-192	Linear (APS)	❏ Yes ❏ No	
OTHER_____	Linear (APS)	❏ Yes ❏ No	
STS-1/OC-1	Ring	❏ Yes ❏ No	
STS-3/OC-3	Ring	❏ Yes ❏ No	
STS-12/OC-12	Ring	❏ Yes ❏ No	
STS-48/OC-48	Ring	❏ Yes ❏ No	
STS-192/OC-192	Ring	❏ Yes ❏ No	
OTHER_____	Ring	❏ Yes ❏ No	

2. Does your company use SONET or ATM transmission systems in its network to support key services?

	Currently Use These Products	Plan to First Use in Next 1-3 Years	Plan to First Use in Next 4-6 Years	Plan to First Use After 7 Years	Do Not Plan to Deploy These Products
Linear SONET Transmission Systems	❏	❏	❏	❏	❏
Ring SONET Transmission Systems	❏	❏	❏	❏	❏
SONET Cross Connects	❏	❏	❏	❏	❏
ATM Switches or ATM Cross Connects or ATM MUXs	❏	❏	❏	❏	❏

3. What is your company's current total number of DS0-equivalent circuit miles, including all transmission technologies (approximately)? _____

4. What percentage of DS0-equivalent miles referred to in Question 3 are supported by each type of transmission system listed below?

	Percentage of DS0 Equivalent Circuit Miles	Percentage of DS0 Equivalent Miles that Use Physical Diversity	Percentage of DS0 Equivalent Miles that **DO NOT** Use Physical Diversity
Linear (APS) SONET Transmission Systems			
Ring SONET Transmission Systems			
SONET Cross Connects			
ATM Switches or ATM Cross Connects or ATM MUXs			
Non SONET/ATM Transmission Products			

5. Do you track outages greater than approximately 60 ms on:

      Linear SONET Transmission Systems   ❏ Yes ❏ No
      Ring SONET Transmission Systems   ❏ Yes ❏ No
      SONET Cross Connects   ❏ Yes ❏ No
      ATM Switches or ATM Cross Connects or ATM MUXs   ❏ Yes ❏ No

6. Do you consider a successful switchover (less than or equal to approximately 60 ms) of the SONET ring an outage?   ❏ Yes ❏ No

7. Do you track successful SONET ring switchovers?   ❏ Yes ❏ No

      If so, how many total successful ring switchovers occur per year (on average)? _____

8. Do you track unsuccessful SONET ring switchovers (greater than approximately 60 ms outage)?   ❏ Yes ❏ No

      If so, how many total unsuccessful ring switchovers occur per year (on average)? _____

9. Do you plan to use SONET Cross Connects for restoration?

❑ Yes ❑ No

10. Use the table listed below to describe the ATM switching elements (not terminal elements) in use in your network:

Capacity	Number of Nodes	Total Number of Ports in Use For All Nodes				
		OC-12	OC-3	DS-3	DS-1	Other
5 GB.						
10GB.						
20GB						
OTHER						

11. What type of survivability architecture is planned in your ATM network? Please check all that apply.

_____Physical Port Protection Switching
_____Logical Path protection switching
_____Other, please describe _____
_____None

12. Does your company have special procedures and/or standards to assure reliability?

In SONET?   ❑ Yes ❑ No

    If yes, please describe_____

In ATM?   ❑ Yes ❑ No

    If yes, please describe_____

13. What are your recommendations to be followed by the industry for Best Practices involved with providing and interconnecting SONET and ATM networks carrying key services?

_____

Appendix C - New Technology Reliability Template

The New Technology Reliability Template is a generic template that can serve as a reliability screen for assessing the reliability of new network technologies. It would be used primarily by a service provider but also is useful to a supplier of the particular technology to understand the important reliability criteria from the service provider's perspective. A person or organization in the service provider company who has primary responsibility for network reliability, planning for integration of a new technology, or overall technical responsibility for a network would be potential users. These potential user's need to assure that all of the issues in the template have been adequately considered/addressed before the technology is integrated into the network. This template could be used as part of the service provider's process for the rapid and reliable evolution of their telecommunications networks.

New Technology Reliability Template

Criteria	Comments
1.0 Architecture	
Technology complies with industry/company standard architecture	
Specific architecture and its reliability features	
Architecture is robust enough to prevent FCC reportable outage	
Worst case percentage of key services restorable with this technology	
New operations support systems identified and meet architectural guidelines	
All changes to existing (legacy) systems have been identified	
Disaster recovery requirements identified and addressed	
Official network interfaces consistent with networking architectural plans and guidelines	
Industry "best practices" exist and have been considered	
List industry "best practices" to be followed	
Architecture is robust enough to meet customer reliability requirements	
Mechanism exists to evaluate end-to-end customer reliability for key services	
Customers have such a mechanism	
If so, what is observed reliability?	

New Technology Reliability Template

2.0 Technology Reliability	Comments
Technology reliability criteria defined	
Supplier documentation of reliability reviewed and meets criteria	
Operations support systems reliability criteria defined and met	
Is provision of key services using this technology as reliable as with current technology?	
For each major failure mode of the technology providing key services, list:	
Describe the failure mode	
What is the failure mode impact in terms of equivalent blocked calls?	
What is the estimated duration of the failure mode?	
What is the estimated frequency of the failure mode?	
What actions(s) are required to recover from the failure mode?	
3.0 Installation	
Standard equipment configurations developed	
Installation methods and procedures developed	
Acceptance procedures documented	

New Technology Reliability Template

4.0 Service Provisioning	Comments
Service order documents have sufficient detail for field personnel and network element administration	
Service provisioning methods and procedures developed	
Feature interaction testing plan developed	
5.0 Monitoring	
Availability objectives exist	
Technology has self-diagnostic and auditing capabilities	
Technology can be remotely monitored and is consistent with existing monitoring system architecture	
Technology has full alarming capabilities	
Monitoring methods and procedures developed	
Required changes to monitoring systems completed	
Network element and OSS tested to ensure surveillance integrity	

New Technology Reliability Template

6.0 Maintenance/Repair	Comments
Technology operation consistent with current maintenance process flow and supporting systems	
Routine maintenance methods, procedures and time frames developed	
Software maintenance plans exist	
Non-intrusive software change/maintenance capabilities exist	
Appropriate test tools/equipment selected and available	
Remote testing and inventory capability exists	
OSS provides technology work force management reports	
Troubleshooting procedures exist including fault visibility, trouble verification and isolation, recovery/repair	
Is operator action or conformation required to recover from failures?	
Post-mortem analysis methods exist	
Process exists to feedback findings and recommendations to improve future reliability	

New Technology Reliability Template

7.0 Interoperability	Comments
Does this technology interoperate with other networks in provision of key services?	
How does the technology achieve reliable operation when interconnecting?	
How is reliable operation monitored and controlled?	
8.0 Training	
Required training courses available in time frames consistent with deployment schedule	
List required training	
9.0 Reliability Monitoring	
Process to collect outage data exists	
Process to do root cause analysis on outage data exists	
Process to develop best practices to improve new technology reliability exists	

Appendix D - Detailed Outage Report

Detailed Outage Tracking Report

Section 1. General Information

Name of LEC or IEC:_____

Location of failure (city, state, office):_____

Environment (staffed, unstaffed):_____

Failure date:_____

Starting time (hour:minute, AM or PM)_____

Duration of outage or incident (minutes):_____

Equipment vendor/model:_____

Software release:_____

Did the responding craft have formal training on the affected DCS?
    ___ Yes   ___ No

Who responded to the outage or incident? (check all that apply)
    ___Central Group (Tier 1)
    ___Support Group (Tier 2)
    ___Vendor
    ___Local craft only

Did the responsible craft have duties other than SONET/ATM (circle one) maintenance and operations?

Was the equipment connected to Operations Support Systems (OSSs)?
    ___OPS/INE ___NMA   ___ITS
    ___Other (specify system and software release:_____)
    ___None

Language used in Craft Interface
    ___ PDS   ___ TL1   ___ Menu-Driven   ___Other _____

Section 2. Breadth and Depth of Failure

Number of affected working channels and interfaces (fill in table)

Kind of Channel	Number of Affected Working Channels	Number of Working Channels
DS1		
DS3/STS1/OC1		
STS3/OC3		
OC12		
OC24 or higher speed		

 (Note that the number of affected channels, not boards, should be entered in the table. For example, if seven DS1 interface boards are affected, and each board interfaces eight working DS1 channels, then 7 x 8 = 56 should be entered above.)

What was the type of system?

    ____ Linear SONET

    ____ SONET Ring

    ____ SONET Cross-Connect

    ____ ATM Cross-Connect

To calculate the outage index, first determine the outage weights, (service weight Ws, duration weight Wd, and magnitude Wm) from the three tables below as defined by T1.A1:

Service Weights:

	IntraLATA Intraoffice	IntraLATA Interoffice	InterLATA Interoffice	911
Service Weight (Ws)	1	2	2	3

Duration Weights:

Outage Duration (minutes)	Duration Weight (Wd)
Less than 2	0.01
2 to 14	0.1
15 to 29	0.5
30 to 59	1.0
60 to 119	1.5
120 to 359	2.0
360 to 719	2.3
720 or more	2.5

Magnitude Weights

Number of Customers Affected (1000s)	Magnitude Weight (Wm)
Less than 10	0.01
10 to 29	0.1
30 to 49	0.5
50 to 74	1.0
75 to 99	2.0
100 to 199	4.0
200 to 499	7.0
500 to 999	10.0
1000 or more	12.0

Calculate the **Outage Index**: _____

Outage Index = Sum of Product of Ws(j)*Wd*(j)Wm(j) for each outage, where j= 1,..., N are the services.

What was the equivalent number of blocked calls for this outage?

_____

Impact on affect channels (check all that apply)

      ___Complete loss of service (no transmission or affected channels)
      ___Loss of reconfigurability function
      ___Loss of alarm visibility
      ___Loss of protection switching function
      ___Loss of ability to communicate with processor
      ___Other (describe):

What was the first indication of trouble? (check all that apply)

      ___Local alarm
      ___Remote (OSS) alarms
      ___Customer complaint
      ___Routine maintenance
      ___Other (describe):_____

Section 3. Cause(s) of Failure

If more than one cause contributed, check all applicable causes.

      ___ Hardware failure
      ___ Firmware failure
      ___ Software failure
      ___ Procedural error of telephone company (failure to follow documented instructions or data entry error)
      ___ Documentation unavailable or out of date
      ___ Error in vendor documentation
      ___ Error by vendor personnel (including personnel from SONET/ATM vendor and other vendors in telephone company office)
      ___ Act of God (including lightning and natural disasters)
      ___ Scheduled event (including scheduled loads of configuration maps or generic software, and any other scheduled craft activity that results in loss of service or function)
      ___ Environmental (including contamination, leaks, building temperature, etc.)
      ___ Operations support system failure (specify system and release: _____)
      ___ Other (including power failure and failure of connecting equipment specify _____)

Describe how the failure occurred. (Example: while rewriting the configuration map on one memory unit, the other memory unit hardware failed.)

_____

_____

_____

Section 4. Trouble Resolution, Observations, and Recommendations for Preventing Recurrences.

Trouble resolution (check all that apply)

    ___ Trouble was resolved by remote intervention

    ___ Trouble was resolved by local craft.

    ___ Trouble was resolved by/with vendor assistance.

    ___ Trouble was resolved by/with assistance of Tier 2 Technical Support (RTAC, ESAC, etc.)

Was there any delay due to dispatch of field forces?

    ___ Yes   ___ No

Describe how the trouble was resolved.

_____

_____

_____

Provide any suggestions you may have for avoiding similar problems in the future. These may include suggestions for SONET/ATM features, features in connecting systems including Operations Support Systems, documentation changes, increased or different training, or any other relevant area.

_____

_____

_____

Appendix E - SONET Tutorial

E.1 What is SONET?

Synchronous Optical Network (SONET) is a set of optical interface standards proposed by Bellcore to ANSI T1 committees in 1984 for optical communications. Its original objective was to produce a common standard for all fiber-optic transmission equipment to achieve mid-span meet and network interoperability purposes under multiple suppliers' environment. Since then, ANSI has defined SONET standards extensively in many areas through various phases. Phase I includes the rates and formats definitions and the optical interface characteristics. Phase II includes an electrical interface characteristics, data communication channel protocols, and SONET OAM&P functions. Phase III includes the message sets carried over the data communication channels (DCCs), jitter specifications, synchronization status message, and automatic protection switching (APS) protocols on linear and ring networks. As defined in the ANSI T1.105 standards during Phase I, a hierarchy of SONET rates and formats for each SONET Optical Carrier at Level N (OC-N) have been specified, where N is either 1, 3, 12, 24, 48, or 192. The base signal for SONET is OC-1 at the 51.84 Mbps rate. The transmission rate for any other signal level OC-N is simply at the N x 51.84 Mbps rate. The SONET standards are mainly used in the United States and Canada to support DS1 basic bit rate at 1.544 Mbps.

The counterpart of the SONET optical interface standards used in the European Community and other countries is called Synchronous Digital Hierarchy (SDH). The ITU-T Standard Study Group (formerly called CCITT) has designed their version of optical interface standards based on ANSI SONET standards since 1986 to create a worldwide standard for SDH to support the E1 basic bit rate at 2.048 Mbps.

The basic SONET frame format is called the Synchronous Transport Signal - Level 1 (STS-1). The basic SDH frame format is called the Synchronous Transport Module - Level 1 (STM-1), which has the exact transmission rate as SONET OC-3 signal at 155.52 Mbps rate. Up to now, the SONET and SDH standards are essential the same beyond the STS-3 or STM-1 level, although there exist some discrepancies in the basic frame format.

E.2 How Key Services are Provided in SONET

The SONET STS-1 frame consists of 9 rows by 90 columns of octets, for a total of 810 bytes. Of these, 9 octets are assigned for section overhead, and 18 octets for line overhead. The functions provided by the section overhead include frame alignment, section parity check, orderwire, section DCCs, and user channels. The functions provided by the line overhead include STS payload pointer, line parity check, APS channel, and line DCC. The rest of the 783 bytes in the STS-1 frame, which is called the Synchronous Payload Envelope (SPE), contains STS path overhead, STS-1 Payload Capacity and fixed stuff bytes. The functions of STS path overhead include STS path trace, STS path signal label, and STS path status. The SONET payload capacity is used to carry the actual information, such as DS3 and DS1 voice service through STS-

1 and sub-STS-1 payload mappings. When DS1 service is supported, the Virtual Tributary (VT) structured STS-1 SPE will be applied and a set of VT path overheads will be generated. Since SONET has recently been selected as the transport medium for Asynchronous Transfer Mode (ATM), it can be used to carry other types of traffic, such as data, video, image and multimedia, as well.

E.3 Taxonomy of SONET Ring Types

The types of SONET network elements (NE) can be categorized as either Regenerator, Terminal (TM), Add/Drop Multiplexer (ADM), or Digital Cross-connect System (DCS). A SONET Regenerator is used to enhance the optical signal and it usually contains two pair of working fibers and two pair of protection fibers at both the east and west high-speed interface sides. No optical or electrical low-speed interfaces at the drop ports are required for a Regenerator. A SONET TM usually contains two pair of OC-N high-speed optical fibers. However, all four fibers are located at a single line interface side with two fibers for working and the other two fibers for protection. A SONET ADM usually contains four pairs of OC-N high-speed optical fibers., one working pair and one protection pair of fibers are located at each east side and west side. A SONET DCS usually contains more than two pairs of optical interfaces with possibly different OC-N rates. Regardless of the differences in their equipment types, all of the above SONET NEs except for the SONET Regenerator can add, drop, and pass-through/cross-connect a low-speed signal, such as DS1 and/or DS3, at their drop ports.

The types of SONET network architecture include linear, ring or mesh configurations. A linear network is usually configured by two or more SONET TMs or ADMs to provided point-to-point paths between two locations. A ring network is defined as a set of SONET NEs with ring capabilities connecting with fibers to form a closed loop. Note that the protection switching scheme in a ring network can be in either path-switched or line-switched mode. Also note that the traffic on a ring network can also be routed either unidirectionally or bidirectionally. Currently, the three commercially available SONET ring network types are: (1) two-fiber unidirectional path-switched ring (UPSR), (2) two-fiber bidirectional line-switched ring(2-f BLSR), and (3) four-fiber bidirectional line-switched ring (4-f BLSR). A mesh network is usually composed of a set of SONET DCSs to support multiple alternate routes for traffic restoration when a working route in the network is cut. All of the above SONET networks have been successfully and widely deployed currently in both the United States and Canada.

A linear network uses a linear APS protocol carried on the line APS overhead bytes to coordinate line protection switching between a pair of SONET line terminating equipment (LTE). Note that four fibers are required to connect these two LTEs, two for working traffic and two for protection. Two possible line protection switching schemes are supported: 1+1 and 1:1 mode. Under normal condition, the traffic is routed on the working fibers. However, the linear system with 1+1 protection switching mode will also carry traffic on the protection fiber simultaneously. If the working fibers are cut, the traffic will be switched and selected from the protection fibers via linear APS protocol. The linear system with 1:1 protection switching mode will carry the

traffic only on the working fiber under normal conditions. If the working fibers are cut, the traffic is switched to the protection fibers via the coordination of the linear APS protocol.

A UPSR network uses two fibers to connect each adjacent node in the ring to form two counter-rotating rings, one for working channels and one for protection. Two duplicated signals are sent from a source node and received at a destination node by traveling on different ring paths. These two signals are constantly monitored for their signal performance level by a device called the path selector located at a destination node. A path selector at each drop port will always select the signal from the better of the two duplicated signals it receives.

A 2-f BLSR requires only two fibers to connect each adjacent node in the ring to form a closed loop. Note that each fiber carries both working and protection channels. The first half channels on each fiber are designated as the working channels while the second half channels are for protection. When a fiber span between two adjacent nodes in a ring is cut, the working channels will be bridged to the associated protection channels at one end node to the failed span, traveling around the ring, and selected at the other end node. Thus, the traffic routed over the failed span can be restored. This type of protection switching scheme used in a 2-f BLSR is called ring switch. The ring switching mechanism of a ring switch is coordinated via a ring APS protocol carried on the line APS overhead bytes.

A 4-f BLSR requires four fibers to connect each adjacent node in the ring, two fibers are for carrying working traffic and two for protection. Similar to a ring switch used in a 2-f BLSR, when all four fibers on a span in a 4-f BLSR are cut, the traffic on the working fibers will be bridged to the protection fibers at one end node, traveling around the ring, and selected at the other end node. This type of protection switching scheme is also called ring switch in a 4-f BLSR. In addition, a 4-f BLSR also supports another type of protection switching scheme called span switch. Similar to a linear protection scheme, a span switch in a 4-f BLSR will restore traffic on a failed span by bridging and switching the traffic from the working fibers onto the protection fibers when only the working fibers are cut on that span. Both the ring switching and span switching mechanism in a 4-f BLSR are coordinated via a ring APS protocol carried on the line APS overhead bytes.

E.4 SONET Based DCS Mesh Network and Its Restoration

A mesh network uses DCS reconfigurability to restore traffic in case of network failures. By changing connections, DCS reconfiguration methods restore service by routing failed demands on one or more alternate routes. Such a restoration mechanism is useful to protect against major failure events (e.g., multiple node and/or link failures). There are two network restoration approaches to support network survivability via reconfiguration of DCSs in self-healing mesh network: Centralized, and Distributed. These approaches are based on the method of controlling the reconfiguration of the DCSs. In the centralized approach, all the coordination of the search for alternate paths and path rerouting goes through a centralized system. The centralized controller contains all the information needed to control and reconfigure the affected DCSs. In a distributed control approach, the DCSs in the mesh network coordinate among themselves with

corresponding reconfiguration around the failure. The process of searching for alternate paths and rerouting is done through the exchange of restoration message among the participating DCS nodes and executing the algorithm which is stored in each node. The distributed control algorithm may be executed either in a dynamic fashion in real time or using pre-planned routing tables stored in each DCS.

The required protection switching times for the length of hits in both linear and ring networks are within 50 milliseconds for each single signal failure event, and 100 milliseconds for second and successive ring multiple signal failure events. The traffic restoration times in a DCS mesh network are estimated as about several minutes for the centralized approach, and several seconds, for the distributed approach. The centralized approach may require use of an element manager to manage a subset of the DCS nodes in the network, while a centralized system (e.g., an OS) coordinates the information between element managers.

E.5 What are Some Failure Modes?

Examples of SONET facility signal failure modes include Loss of Signal (LOS), Loss of Frame (LOF), Loss of STS Pointer (LOP), line BER exceeding a preselected threshold (SF), line Signal Degrade (SD), line AIS, path AIS, path LOP, path Unequipped Signal Label, path signal mismatch, path SF, path SD, and path Payload Defect Indication (PDI). Example of SONET equipment hard failure modes include low-speed circuit pack failure, high-speed circuit pack failure, protection switching card failure, APS controller failure, power card failure and memory processor device failure. Examples of user error modes include improper provisioning, improper operations, improper firmware upgrade, improper network upgrade (e.g., ring node addition), improper memory administration, and improper maintenance procedures.

Most of the single facility failure events can be protected by either using route diversity in a linear network, designating protection channel capacity in both UPSR and BLSR networks, or applying dynamic or pre-planned alternate route approach in DCS mesh network. Similarly, most of the single equipment failure events can be protected by providing redundant protection units and protection switching control units at a node. Many of the double failure modes are difficult, if not impossible, to protect against, but simultaneous failure scenarios are usually rare. Examples of some double failure modes include failures of both working and protection units at a node, simultaneous fiber cuts occurred in a BLSR, a single fiber cut occurred while a Forced Switch (FS) command triggered in a ring, and two simultaneous FS commands triggered in ring. Note that two simultaneous FS commands triggered in a ring would cause the ring to be segmented into two rings. and the traffic from one ring segment will no longer be able to be transported to the other ring segment. Some worst-case scenarios of SONET failure modes include natural disaster in a large area such as hurricane, earthquake, flood and fire, and severe human errors such as accidental deletion of circuit cross-connections, deletion of ring map, disconnecting in-service fibers, and software bugs found in protocol, routing or restoration algorithms. A disaster recovery contingency plan is usually needed and frequently reviewed in order to reduce the cost and damage due to any of the above severe failure modes to the maximum extent.

For traffic which is routed through various SONET equipment from multiple equipment suppliers, the SONET interoperability objective is extremely important. Examples of end-to-end SONET interoperability issues among multiple suppliers include differences in operations communication interface (e.g., using Translation Language one (TL1) vs. Common Management Information Service Element (CMISE)), differences in linear and ring APS protocols, differences in signal selection criteria at a path selector and service selector, differences in unused and proprietary SONET overhead bytes, and differences in adopting new ANSI standards (e.g., PDI and synchronization status message). All of the above differences among multi-supplier SONET equipment will have some impact on the desired level of signal performance and reliability of the traffic routed on them. An interoperability test, conducted either at a laboratory or in the field, can help to identify and resolve most of the above issues.

Appendix F - SONET-Based DCS Restoration

The material in this section is excerpted with Bellcore permission from "Restoration of DCS Mesh Networks with Distributed Control: Equipment Framework Generic Criteria," Bellcore, Framework Technical Advisory FA-NWT-001353, Issue 1, December 1992.

F.1 Introduction

The potential for catastrophic failures in today's high-capacity, fiber-optic transport networks has made network survivability a prime concern for Local Exchange Carriers (LECs). Fiber-optic (e.g., Synchronous Optical Network [SONET]) equipment provides high bandwidth and high traffic capacity, but in return requires high reliability/survivability. Incorporating more survivability into the network has been addressed with such network topologies as SONET Automatic Protection Switching (APS)[1] and SONET rings-[2] [3] The realization of network survivability can also be addressed with Digital Cross-Connect System (DCS) networks.

The DCS network, in particular a mesh network, is a likely topology to be deployed in future transport networks because of its usefulness for bandwidth management and because currently installed network infrastructures may already support it. One approach to enhance the survivability of DCS mesh networks is to use the DCS reconfigurability for restoration purposes. Restoration based on DCS reconfiguration can supplement other failure recovery methods, such as SONET APS with diverse protection, in cases of catastrophic failure, such as a central office fire, a DCS node failure, or multiple failures.

Two types of DCS restoration methods exist: centralized restoration and distributed restoration. In centralized DCS restoration systems (Figure F.1), which have been implemented today, an Operations System (OS) controls the rerouting of traffiic around the failure. Control of the process is centered at the OS - hence the term "centralized control."
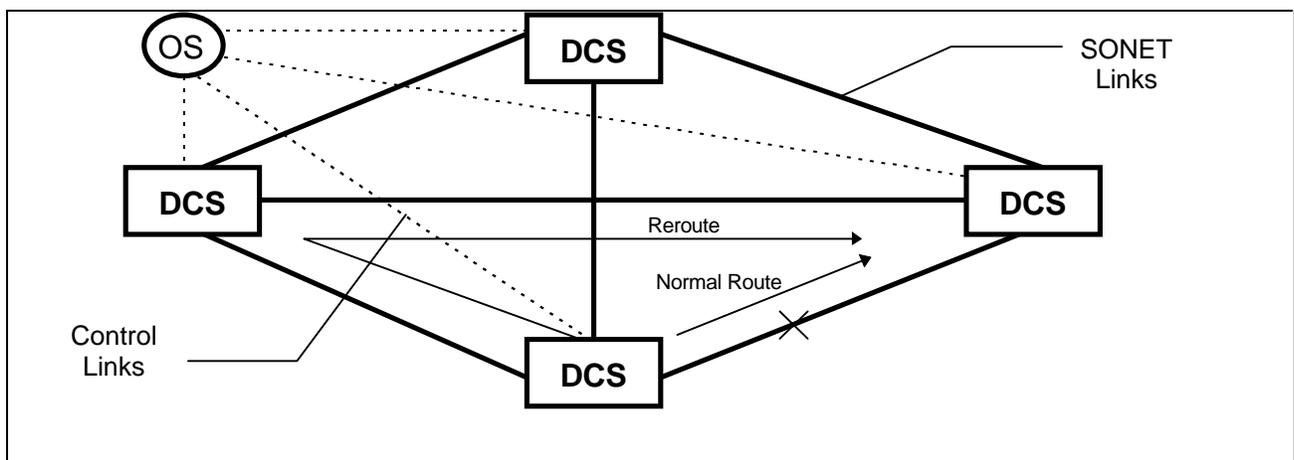

Figure F.1 - DCS Centralized Control Architecture

In distributed DCS restoration systems (Figure F.2), the DCSs control rerouting of traffic; the algorithm controlling the restoration is programmed into each DCS in the network. At the time of failure, if "first line of defense" survivability methods (such as APS) do not completely restore
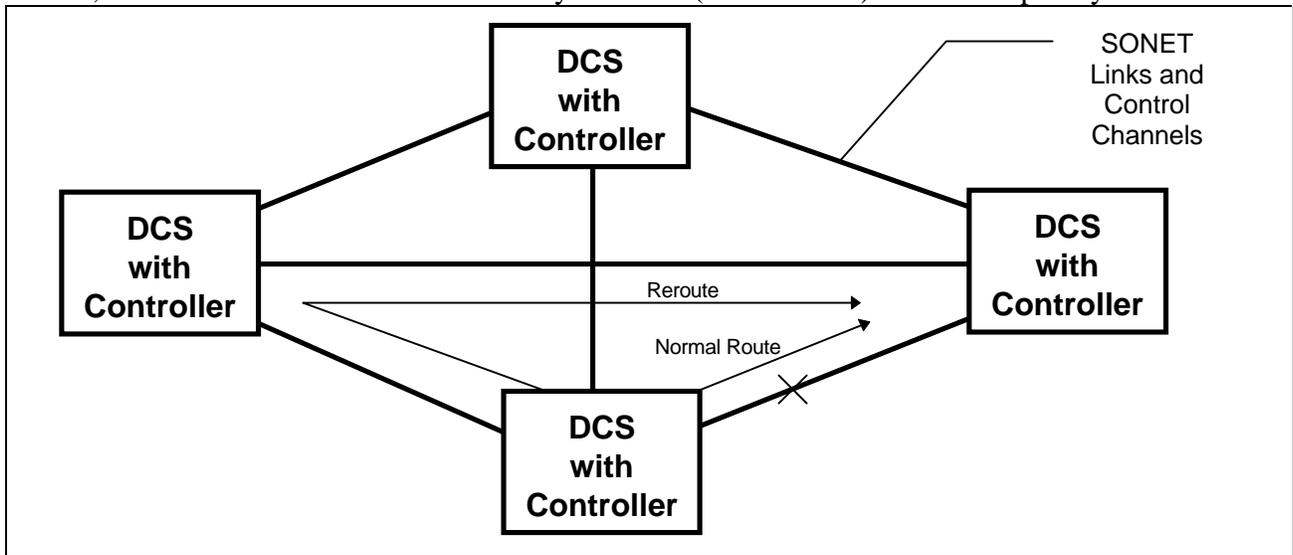

Figure F.2 - DCS Distributed Control Architecture

lost traffic, the DCSs with distributed control exchange messages (via signaling control channels) and coordinate activities among themselves to reroute the traffic. Control of the process is shared among the DCSs in the network.

F.2 Motivations for DCS Distributed Control Restoration

Wideband and broadband DCSs[4] are considered intelligent Network Elements (NEs) in transport networks. They serve as a convenient way to groom traffic and provide network facility management functions to the present network, as well as to the evolving SONET structure. Given that the DCSs will be employed in LEC networks, it may be economically beneficial to take advantage of the DCSs to provide a portion of the network survivability strategy (or the entire strategy) for the core network.

Restoration based on DCS reconfiguration provides protection against major failure events, including node and multiple failures; this is an important reason for considering DCS reconfiguration for restoration purposes. Distributed control DCS reconfiguration is preferred over centralized control provided the architecure can be developed at a reasonable cost. A companion Special Report, SR-NWT-002514, The *Role of Digital Cross-Connect Systems in Transport Network Survivability,*[5] is planned that will summarize Bellcore's studies and preliminary conclusions regarding restoration in DCS networks, including distributed control of restoration. This SR will provide the metrics for comparing DCS mesh architectures with distributed control restoration relative to other survivable architectures. The results indicate that DCS mesh networks are economical for areas with high demand and connectivity, and would have

low expected loss of traffic and low average expected downtime of connection. They also rank highly among the most survivable networks under node failure scenarios.

In addition, when compared to centrally controlled schemes, the DCS mesh network with distributed control is more reliable (in terms of a guaranteed signalling communications channel) and faster. Regarding the latter, distributed control has the potential to exhibit much faster restoral times than centralized control (seconds versus minutes), which is the main motivation for considering DCS reconfiguration schemes with distributed control algorithms. This architecture may optimize the combination of survivability, economics, speed of restoration, technology, and market evolution.

Other benefits of this architecture may be that it could provide a common (distributed) approach to restoration, provisioning (i.e., high-speed service call setup), and testing (i.e., automatic trunk testing) via the signaling control channel. This Framework Advisory does not address these other possible benefits.

F.3 Restoration Speed

Speed of restoration is a prominent issue. At the moment, Bellcore is aware of technologies that can help reduce distributed control restoration times to seconds (e.g., 2 to 20 seconds, depending on the DCS's cross-connection time). However, new technologies are needed to achieve times below 2 seconds for every restored link.

Distributed control restoration is essentially a sequential process. Namely, if an OC-48 fails, the first STS-1 may be restored in 100 to 200 ms using present DCS crossconnection technology, whereas restoring the last STS-1 may take up to several seconds. Restoration times greater than 2 seconds are not viewed as sufficient for most services to use this technology as the sole restoration vehicle for the core network. An NRT of less than 2 seconds is considered a target for DCS distributed control restoration since most services are minimally affected with an NRT of less than 2 seconds. This implies that, for the moment, DCSs cannot take over all restoration functions, but perhaps should be used as a back-up to other faster forms of survivability (e.g., diverse protection APS, rings) rather than as a primary survivable architecture.

APS and rings provide approximately 50 ms total service restoration. Service outages under 50 ms will be "transparent" to most users. DCS distributed restoration schemes could add another layer of survivability to protect against larger failure events (multiple failures, node failures, or other failure types), thereby increasing overall network survivability. For example, a ring architecture could be used to protect against single events, and a mesh architecture could serve as a backup for more catastrophic failures. This type of application is referred to as providing "background" survivability.

In this application, the economic advantage of using DCSs for restoration may not be large, but maximum survivability is obtained for minimum cost. For the DCSs to take over the entire survivability administration for the core network requires a fast distributed control restoration

technology. Alternately, one way to achieve a 2-second total restoration time is with a priority restoration scheme. Priority restoration (i.e., grooming high priority services such as DS0s, DS1s, VTs, DS3s, STS-1s into specific STS-1s that can be restored first in time frames much less than 2 seconds using a priority control scheme) is undesirable to some LECS, mainly because of administration difficulties that will exist until reliable, mechanized bandwidth management capabilities are deployed. Grooming priority services planning and engineering efforts for developing and evolving the network accordingly. Note that, in practical cases, high priority services may make up 10 to 20 percent of total circuits being restored.

Bellcore requests more interaction with industry to determine the technical feasibility of improving distributed control restoration times enough to use this technology as the sole restoration vehicle for the core network.

The overall goal of distributed restoration is to provide restoration as fast as possible with an end-to-end service restoration objective of 2 seconds or less. This means that the last path (e.g., STS-1) would be restored in 2 seconds or less. Presumably, all other failed paths would be restored in less than 2 seconds.

F.4 Distributed Algorithms for Restoration

There are two basic types of distributed algorithms: dynamic and preplanned. All distributed algorithms use the spare capacity available in the network to provide alternate routes for failed circuits or a failed facility. Note that a sufficient amount of spare capacity must be designed into the network for distributed algorithms to work efficiently and restore (or guarantee) as much affected traffic as possible over all possible network failures. It is assumed that spare capacity assignment will be done by an external planning tool. The dynamic, distributed algorithms for restoration in DCS mesh networks can be generally described as a phased process. Some algorithms use three phases. However, other algorithms may only have two phases. The algorithm rules reside in the DCS operations controller.

The algorithm is normally triggered after DCSs indicate an alarm condition (e.g., Alarm Indication Signal [AIS], Loss of Signal [LOS], Loss of Frame [LOF]), including additional time for physical level protection to occur. During the first (flood or broadcast) phase, information is distributed around the network, notifying all available DCSs of the failure and enabling them to participate in finding alternate routes. In the first phase, messages are distributed through the network based on particular broadcasting rules. These messages are originated by one of the nodes affected by the failure. This node can be determined *a priori* at the time of failure (e-g., based on rank order of node ID) or when the services are provisioned. The originating node is also termed the "sender node," i.e., the node receiving a failure condition, whereas the other terminating node is termed the "chooser node." The remaining nodes are intermediate nodes. The flood of messages continues until a path is found to the other affected nodes.

ln the second phase, restoration messages are sent back toward the originating node along the best selected alternate routes, and spare capacity for rerouting traffic is identified and reserved

based on particular setup (or selection) rules- In the last phase, called the "connect" or "confirmation" phase, each DCS node in the confirmed restoration path makes its individual crossconnects to restore each affected STS-1.

The three phases may be recycled until all or most affected circuits are restored. The Network Restoration Ratio (NRR) is the ratio of the number of restored circuits (e.g., STS-1s) to the total number of failed circuits. The NRR depends on such factors as network spare capacity assignment and the timeout (or retry limit). The latter is related to the network size, i.e., number of nodes and number of links. To help control the amount of recycling and avoid broadcast message congestion, distributed algorithms use information such as hop count limits. A "hop" is defined as traversing one @ between DCSs.

An alternate scheme to consider is a preplanned approach. This method has the potential to reduce algorithm execution time (in essence, one phase only) and reconfiguration time because prior knowledge of the internal routes allows pipelining of internal communications. Basically, in the preplanned approach, the failure is conveyed to all DCSs and the appropriate maps are internally downloaded. The preplanned method is more labor intensive (i.e., pre-engineering and planning) and requires that a map be stored in each DCS for each failure scenario. All potential failure scenarios must be addressed, resolved, and avoided. Because this approach requires extensive database updating capabilities, many LECs resist it due to their current experiences with database updating (e.g., difficult to update when changing facility configuration).

F.4.1 Level of Survivability

The restoration technique (Figure F.3) in a given DCS mesh network can either be link (or line) restoration (i.e., routing failed link(s) over alternate links where all traffic is restored intact] or
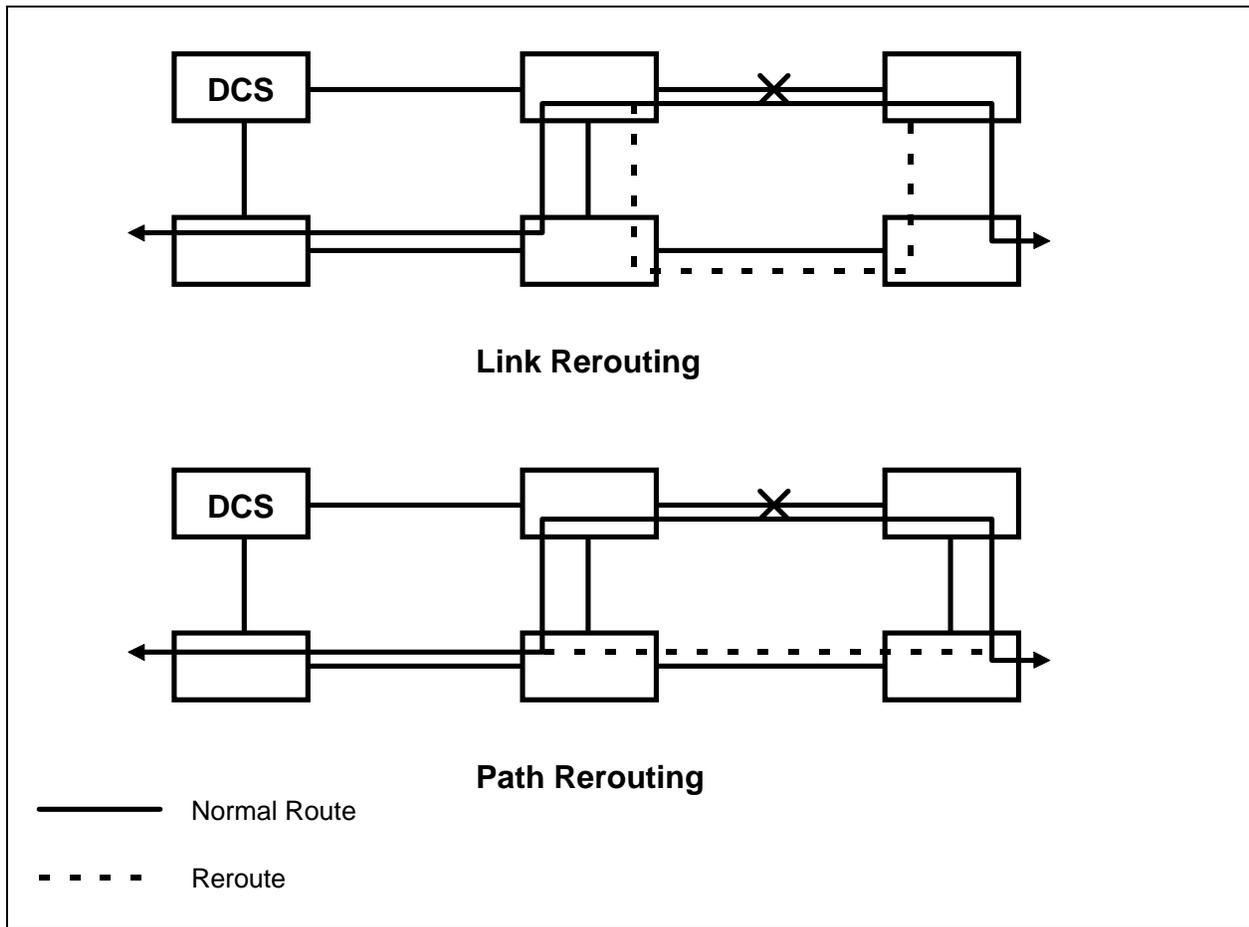
Figure F.3 - DCS Restoration Techniques

path (STS/DS3) restoration (i.e., paths are restored individually on an end-to-end basis and may travel over different links). Line restoration is limited between two line terminating equipment units - normally the nodes adjacent to the failure. Path restoration is normally performed between two path terminating equipment units and is not limited to the nodes adjacent to the failure. A variation of path restoration offers a restoration scheme based on a 2-hop restoration algorithm. A mix of line and path signal restoration is not allowed in a given DCS mesh network.

Both line and path restoration have their advantages and disadvantages. Line restoration can shorten restoration times and make the return-to-normal procedure easier. However, path restoration can make more efficient use of the spare capacity in the network. More importantly, path restoration can handle link failures, multiple failures, or node failures. It is not practical for line restoration to handle multiple failures or node failures because the restoration is localized to the nodes adjacent to the failures. That is, line restoration cannot traverse two or more hops, which would be required to route around a node failure. Path restoration also makes it possible to integrate with other survivable architectures (e.g., rings). In view of this comparison, path restoration is preferred over line restoration.

59

Appendix F References

[1] SR-NWT-001756, *Automatic Protection Switching for SONET*, Issue 1 (Bellcore, October, 1990).

[2] TR-NWT-000496, *SONET Add-Drop Multiplex Equipment (SONET ADM) Generic Criteria: A Unidirectional Dual-Fed, Path Protection Switched Self-Healing Ring Implementation*, Issue 3 (Bellcore, May 1992) Supplement 1 (September 1991). (A module of TSGR, FR-NWT-000440.)

[3] TA-NWT-001230, *SONET Bidirectional Line Switched Ring Equipment Generic Criteria*, Issue 2 (Bellcore, April 1992)

[4] TR-TSY-000233, *Wideband and Broadband Digital Cross-Connect Systems Generic Requirements and Objectives*, Issue 2 (Bellcore, September 1989); plus TA-NWT-000233, Issue 4 (November 1992) (A module of TSGR, FR-NWT-000440.)

[5] SR-NWT-002514, *The Role of Digital Cross-Connect Systems in Transport Network Survivability*, Issue 1 (Bellcore, to be issued).

Appendix G - ATM Switching Tutorial

ATM is a broadband technology, aimed at integrating Voice, Data, and Video and Multimedia services over a common transmission and switching infrastructure. ATM standards and specifications have been developed in both national and international standards bodies, and a wide variety of ATM products have been developed by suppliers. Originally envisioned as the technology of choice for future broadband telecommunications networks, ATM has also been embraced by the data communications industry in both local-and wide area network(LAN and WAN) applications. This has been driven by the increasing bandwidth demands of desktop applications such as computer aided design(CAD), transfer of large database files and various types of multi-media applications. It is expected that ATM will provide the combination of scaleable bandwidth on demand and low end-to-end delay that cannot be efficiently supported by today's network technology.

This Appendix uses material that can be found in References [1], [2] and [3].

G.1 What is ATM?

ATM is a cell-based technology, which uses fixed-length cells, 53 octets long. This contrasts with frame based technology, where variable length units of data are transmitted. In other words, the size of a frame transmitted on a LAN or WAN may vary, depending on the information coming from the higher layer protocol. Frame sizes could contain thousands of octets of user information. The usual frame overhead of headers, trailers, and other typical addressing and error control information is therefore insignificant compared to the frame size.

In ATM, on the other hand cells typically have a 5-octet header(overhead), followed by a 48-octet payload. This results in an rather high overhead ratio (5/53, or 9.4 percent). However, because cells are of fixed length, they may be transmitted at regular intervals. This is useful for all time-sensitive applications such as packetized voice, thus showing the advantage of cell-based technology.

G.2 ATM Protocol Reference Model

The ATM protocol stack is shown in Figure G.1.

LANs	Frame Relay Se•rvice	Constant Bit Rate Emulation (Voice)	Video	TCP/IP
ATM Adaptation Layer **(Service Specific Convergence Sublayer)** **(Segmentation/Reassembly)**				
ATM Layer **(UNI/NNI: Cell Switching**				
Physical Layer **(SONET/DS-3/UTP, etc.)**				

Figure G.1: ATM Protocol Stack

ATM defines four classes of service characterized by:

    a) Whether the service is connection-oriented or connectionless
    b) Whether the bit rate is constant or variable., and
    c) Whether or not there is a timing relationship between the source and destination.

These four service classes are identified as Class A, Class B, Class C and Class D and match with the above characteristics, as shown in Figure G.2:

	Class A	**Class B**	**Class C**	**Class D**
Timing relation between source and destination	**Required**		**Not required**	
Bit rate	**Constant**	**Variable**		
Connection mode	**Connection-oriented**			**Connectionless**
Applications	**Voice, video, circuit emulation**	**Compressed voice or video**	**Frame Relay, X.25 traffic**	**SMDS, LAN traffic**

Figure G.2 - AAL Service Classes

- Class A: Connection oriented, constant-bit rate data with timing relationship between source and destination. Examples include PCM-encoded voice, constant bit-rate video, and DS1 and DS3 circuits.
- Class B: Connection-oriented, variable bit-rate data with timing relationship between source and destination. Examples include compressed audio and video.
- Class C: Connection oriented, variable bit-rate with no timing relationship between source and destination. Examples include Frame Relay and X.25 traffic.
- Class D: Connectionless, variable bit-rate with no timing relationship between source and destination. Examples include SMDS and LAN traffic.

To adapt these four service classes to the common 53-byte cell structure, four ATM Adaptation Layers(AALs) have been developed: AAL Type 1, AAL Type 2, AAL Type 3/4, and AAL Type 5. The mapping between service class and the AAL Type is as follows:

The four different types of AALs have been defined to optimize the four classes of service:

- Class A: AAL Type 1
- Class B: AAL Type 2
- Class C: AAL Type 3/4 and AAL5
- Class D: AAL Type 3/4.

The above associations are not restrictive. In reality, at the present time, only AAL5 and AAL1 are being implemented in ATM products.

G.3 AAL Services:

AAL services enable many functions needed to interface a higher layer protocol like TCP/IP, or Frame Relay to ATM cells. It attempts to make the ATM layer transparent to the higher layer protocols. These are the AAL characteristics:

- Segmentation and Reassembly- Since the data sent for most services will be larger than an ATM cell payload(48 bytes), the AAL provides data segmentation and reassembly function.
- Sequence Numbering- this allows cell loss detection through sequence numbering
- Cyclic Redundancy Check- this provides error checking of cell payloads
- Length Identification: Provides information pertaining to the length of data octets in a partially filled cell.

G.4 Planned Services for ATM: Data, Video, and Voice

As previously stated, ATM was designed to integrate voice, data and video services over a common transmission and switching infrastructure. Examples of services expected to be supported by ATM in the near future include

Data:

a) *LAN Emulation*: ATM needs to support the interworking of the huge embedded base of legacy LANS existing today. Here the approach is to make the ATM protocol to emulate existing LAN services. The LAN Emulation specification defines how an ATM network can emulate a medium access control(MAC) service, such that network layer protocols on legacy LANs like Token Ring, and Ethernet can operate without modifications.

b) *Frame Relay over ATM*: Frame Relay is a well established protocol, while ATM is a relatively new, but rapidly emerging protocol. Therefore, in order to preserve the investment in Frame Relay hardware, while migrating to ATM, a Frame Relay to ATM Implementation Agreement has been developed for both Network and Service interworking.

c) *IP over ATM*: Due to the large existing embedded base of TCP/IP on the national network infrastructure, understanding the performance of TCP/IP on ATM based networks is of great importance. Standard bodies and other such as the IETF and ATM Forum are working to optimize the interaction of TCP/IP with ATM. RFC 1577 IP over ATM: Internet Engineer's Task Force(IETF) defines address mapping solution for IP over ATM network operation. It uses the Address Resolution Protocol(ARP) to map IP addresses to either the ATM E.164 address or an SSAP address. The encapsulation of the Subnetwork Access Protocol-Logical Link Control(SNAP-LLC) inside an AAL5 CPCS is defined in RFC 1483.

Video:

The use of ATM for Multimedia services like Video on Demand(VoD) involves using constant packet rate(CPR) encoded MPEG-2 streams carried over AAL5. Issues under discussion in the ATM Forum include schemes for optimal and high performance encapsulation of MPEG-2 transport streams on AAL5.

The ATM Forum has a document- SAA Audio-visual Multimedia Service(AMS) Agreement, August, 1995 Document number: AMSAI:Vod 1.0. The document specifies the agreement for carrying audio, video, and data over ATM in support of Audio Visual Multimedia Services(AMS). It addresses Video on Demand(VoD) using MPEG-2 transport stream over AAL5. The agreement's scope includes VoD Service Description, Reference Models, System Structure, AAL requirements, ATM Traffic Parameters, ATM Performance Parameters, Network Adaptation, and Signaling Requirements and Enhancements.

Voice and Telephony over ATM

The use of ATM for voice communications will be essential if carriers will have to make ATM ubiquitous, and cheap enough to support multimedia home applications. ATM switches will have to support voice cost-effectively to compete and replace existing TDM T1 and T3 switches, so that a truly integrated ATM based Voice, Video, and Data transport and switching system has to be realized.

Key issues of transporting voice over ATM

a) Reduction of trunk capacity due to ATM's framing procedure overhead. The ITU documents have identified ATM Adaptation Layer 1(AAL1) for constant bit-rate(CBR) or circuit-emulation service(CES). The use of AAL1 reduces the trunk capacity. With 5 bytes of ATM header, plus the one byte AAL1 header, effectively only 47 bytes out of 53 bytes(89 percent of transport capacity) is available for carrying voice payload. The Cell Trunk Bandwidth for carrying a 64 Kbps circuit is 72 Kbps.

In conventional TDM, a 64 Kbps requires 64-kbps of transport capacity. Therefore, an ATM trunk of a given speed can only support up to 89 percent as many channels compared to a TDM trunk. As an example, if DS3 ATM Physical Layer Convergence Procedure(PLCP) is used for carrying voice traffic, then the effective available DS3 bandwidth for carrying payload is about 40.704 Mbps. Now if the 6-byte ATM AAL1 header overhead is factored, it reduces the effective payload for voice down to 36.226 Mbps, i.e. it can carry approximately 566 voice channels (64Kbps PCM channels).

Currently, the ATM Forum Technical Committee SAA/VTOA Sub-Working Group (Document number ATM-Forum/95-0446R3) has a description on interoperability specification, defining the transport of CBR traffic,over ATM, specifically the following types of traffic:

  a) Structured DS1/E1 Nx64 Kbps/s service
  b) Unstructured DS1/E1 (1.544 Mbps or 2.048 Mbps) service.

The document identifies the general arrangement for interworking between B-ISDN and 64 Kbps based ISDN. It specifies the use of B-ISDN Trunking for the transport of narrowband voice or voiceband(including facsimile) services across public ATM networks. The CBR narrowband trunk circuits(i.e. NX64 Kbps channels) are carried within AAL1 ATM cells using Structured Data Transfer mechanism. The associated SS7 N-ISUP Signaling messages may be carried transparently across the ATM network over a separate ATM connection, using the Signaling Adaptation Layer (SAAL) without any conversion between N-ISUP and B-ISUP.

This document is limited in scope in essentially defining the reliable transport of voice data across ATM networks. The document does not address the processing of narrowband signaling. The association between Time Slots of a local and a remote DS1/E1 is fixed, and so is the compression of voice.

The scope of this document would include the following services.

  1) B-ISDN trunking for narrowband services to provide a switched ISDN service through the ATM network
  2) Transport of compressed voice over ATM to increase the number of voice circuits.

Some of the issues that need to be addressed to make Voice over ATM attractive include:

  1) Identification and implementation agreement on voice compression algorithms for ATM

2) Signal translation to ATM SVCs- mapping of CCS for ISDN and CAS for regular touch-tone to ATM SVC setup protocols.
3) Specification of DS3/E3 Circuit Emulation Services
4) Understanding of ATM cell delays, and its effect on echo-delay impairments in an ATM public network environment.
5) Signaling interworking between access protocols involved in Narrowband ISDN and Broadband ISDN, including B-ISUP and N-ISUP.

The Voice Trunking over ATM Ad Hoc group has to date created a draft for DS3/E3 specification. A straw vote is planned for February, 1996. This group will addresses interworking with devices that perform mu-law and a-law encoding of Voiceband information. This effort is planned to go to Straw Vote in April 1996.

G.5 Role of the ATM Forum

The ATM Forum was founded with the objective of speeding up the convergence of standards and the industry. One of the main objectives of the ATM Forum is to promote interoperability between ATM implementations, and to prompt the use of ATM Products and Services. The ATM Forum is not a standards body, but works closely with the International Telecommunications Union(ITU), and the Internet Engineering Task Force(IETF) in developing the definitions of the ATM standards. Currently the ATM Forum has over 700 members, consisting of Suppliers, Service Providers, Software Companies, Test Equipment Manufacturers, Universities, Government Agencies, and others.

G.6 Status of Standards in ATM Forum And IETF for Services Being Implemented Today:

The following is the status of relevant standards in the ATM Forum and the IETF:

1) Voice over ATM :Baseline text for voice and telephony over ATM-ATM trunking for narrowband services-Document number ATM_Forum/95-0446R3.

2) MPEG over ATM: SAA Audio-visual Multimedia Service(AMS) Agreement, August, 1995 Document number: AMSAI:Vod 1.0

3) LAN Emulation over ATM: LAN Emulation Over ATM Specification -Version 1.0 LAN Emulation SWG Drafting Group, ATM-Forum 94-0035R9.

4) Frame Relay over ATM
   a) Frame Relay/ATM PVC Network Interworking Implementation Agreement - The Frame Relay Forum Document Number FRF.5, December 20, 1994.
   b) Frame Relay/ATM PVC Service Interworking Implementation Agreement - The Frame Relay Forum Document Number FRF.8, April 14, 1995.
5) IP over ATM: Classical IP and ARP over ATM: RFC 1577, January 1993.

G.7 Taxonomy of ATM devices

The ATM Forum publishes a guide on ATM Products and Services. Below is a list of products identified by the forum. This list is a good starting point. More devices would be added as the ATM technolology matures and evolves.

- Network Interface
    - Physical layer optical interface
- ATM Host/Network Interface
- ATM Chips
- ATM Switches
    - UNI Interface
    - NNI Interface
    - B-ICI Interface
- ATM DSU
- ATM Multiplexer
- ATM Routers
- ATM Bridges
- ATM Concentrators
- ATM AAL1 Service Units
    - (PBX to cell device)
- ATM AAL5 Service Unit
    - (Data packet to cell device)
- Set-Top Boxes
- ATM Video Servers

G.8 Broad Artificial Categories of ATM Switches

The first and second generation ATM switching products being deployed today cover a wide range of ATM environments. The ATM switches are aimed at being used in local area ATM LANs, enterprise back-bone and wide area public network applications.

ATM LAN Switches:
Switches that provide the ability to switch legacy LAN traffic, provide high speed ATM connectivity, LAN Emulation capability, and virtual networking.

ATM Carrier Switches:
These are switches suitable to be used in public networks. Typically these large bandwidth switches (10-30 Gbps, scaleable to several hundred Gbps) can be used as central office switches, and are planned to be used for supporting large information networks, and to support residential broadband multimedia services.

ATM Edge Node Switches:
These switches typically provide access for non-ATM interfaces like legacy LANs, Frame Relay, DS1 and DS3 circuit emulation to the larger Carrier switches. They are generally placed at the

edge of a carrier network in a central office or can be placed at a customer premise. Their bandwidth range from a few gigabits up to 15 Gbps.

G.9 Features and Functions that vary from ATM switch to ATM switch:

Architecture, throughput performance, Buffer Capacity, Switch Transit Delay, Cell Loss Probability, Interface Rates, Maximum ATM Ports, Switched Virtual Circuit(SVC) capabilities for UNI and NNI, Maximum VP/VCs supported, non-ATM interfaces supported including LAN interfaces and Frame Relay interfaces, support of Multi-protocol over ATM, dynamic routing, Traffic Policing schemes, Congestion and Flow Control mechanisms, and Reliability Features Supported(NEBS Compliant, Redundant Power and Cooling, Automatic Rerouting of Failed Links, Redundant Switch Fabric Module, Hot Swappable Modules to name a few)

G.10 Restoration Strategies

Alternate routing of VPs and VCs is an important means of increasing robustness in ATM networks. A list of alternate routes selected at the time of original call/connection for PVC and SVC services should be pre-established. When direct route due to a facility failure situation is not available, the ATM switch should examine the list of alternate
routes, and find a route with the suitable route. Virtual circuits(VCs) and Virtual Paths(VPs) in ATM networks can have heterogeneous bandwidth and Quality of Service(QOS) requirements that must be taken into account by the route selection algorithms when establishing alternate routes.

ATM level protection switching is an area of under study in the standards and is premature to specify requirements at this time. Presently, there are no contributions in the ATM Forum that discuss the issue of alternate routing for VPS and VCS. Some preliminary work related to protection switching which involved possible uses of VP cross-connect capabilities added to a Digital Cross-Connect to enhance the survivability and robustness of the core transmission network resources is covered in a Bellcore GR-2891, ATM Functionality in SONET Digital Cross-Connect Systems-Generic Criteria(A Module of TSGR, FR-440), Issue 1, August 1995. However, there are requirements for SONET Protection Switching and SONET Ring Restoration under facility and node failure conditions.

[1] ATM Forum Technical Committee SAA/VTOA Sub-working Group, October 2-6, 1995, Document Number ATM_Forum/95-0446R3
[2] T. Nolle, "Voice and ATM: Is Anybody Talking?", *Business Communications Week*, June, 1995
[3] M. A. Miller, *Analyzing Broadband Networks: Frame Relay, SMDS and ATM*, pub. by M&T Books

SONET/ATM Team Report

Dave McDysan, MCI, Chair
11/8/95

Participants: Alcatel, Ameritech, AT&T, Bellcore, Fujitsu, Sprint, Siemens

CHARTER

- Assess reliability impact on key services by SONET/ATM
- Key services include: POTS, 911, Operator Services, Common Channel Signaling
- Survey manufacturers and carriers
- Analyze results
- New technology reliability template
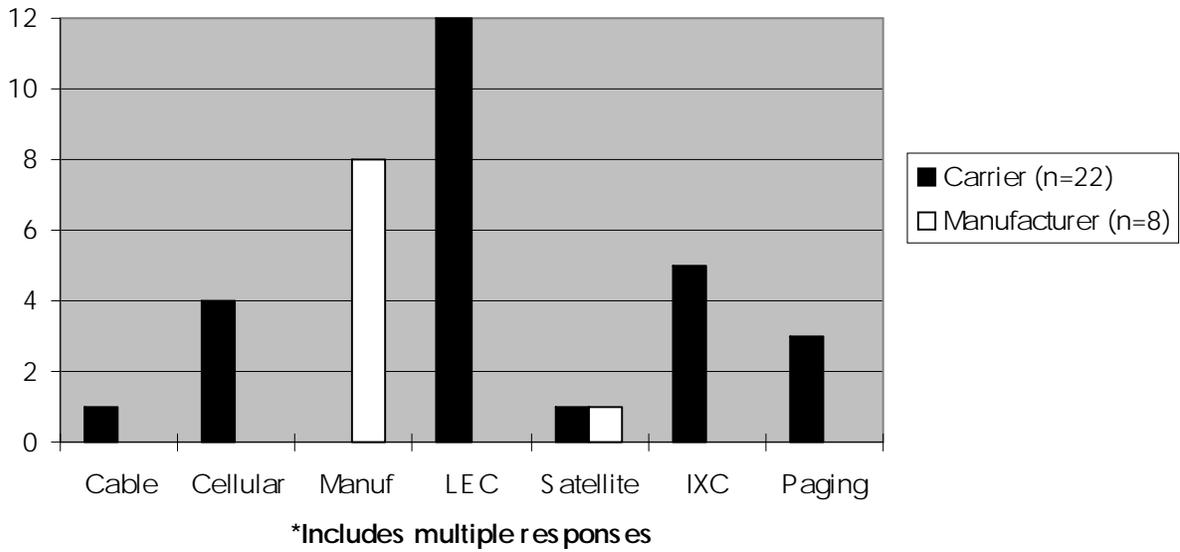- Generate presentations and final report

STATE OF TECHNOLOGY

- Over 80% of carriers provide key services using SONET
- SONET rings protect against single failures of high bit rate SONET
- SONET is over 40% of current deployment
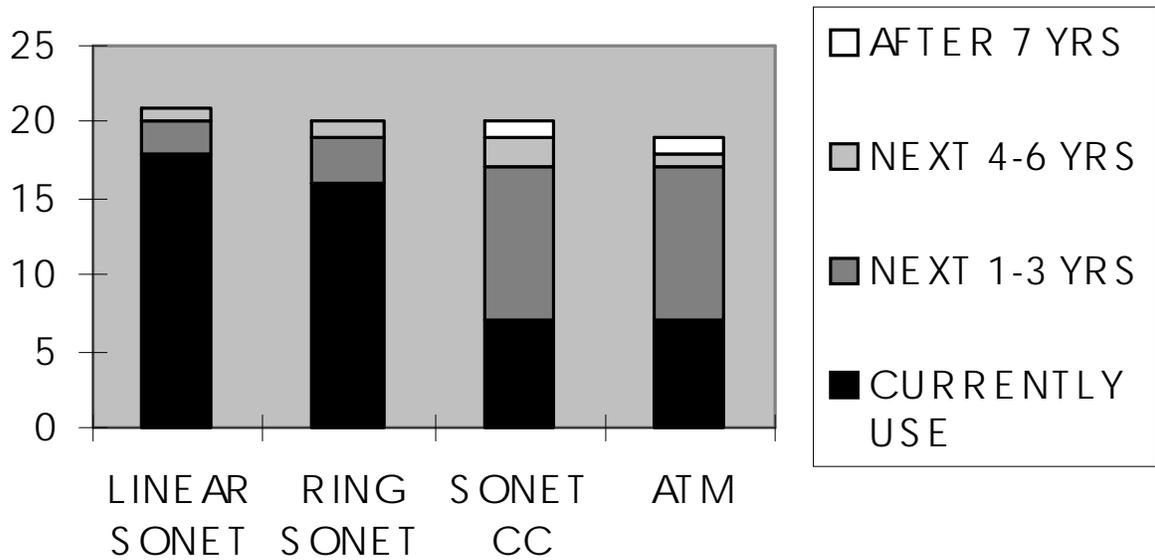- SONET rings are designed to be highly reliable

ANALYSIS OF SURVEY RESULTS

- Cross Industry Segment
- 22 Carriers, 8 Manufacturers responded
- 9 Manufacturer Questions
- 13 Carrier Questions
- Summary conclusions derived by team

Industry Segments Represented*

Legend:
- Carrier (n=22) (black)
- Manufacturer (n=8) (white)

Categories: Cable, Cellular, Manuf, LEC, Satellite, IXC, Paging

*Includes multiple responses

Use of SONET/ATM for Key Services

Legend:
- AFTER 7 YRS
- NEXT 4-6 YRS
- NEXT 1-3 YRS
- CURRENTLY USE

Categories: LINEAR SONET, RING SONET, SONET CC, ATM

STATE OF TECHNOLOGY

- SONET enables architectures that provide high availability
- Interconnection of SONET rings may be a single point of failure
  - e.g., a patch panel, multiplexer or cross-connect
  - Less than 30% of carriers provide services over ATM
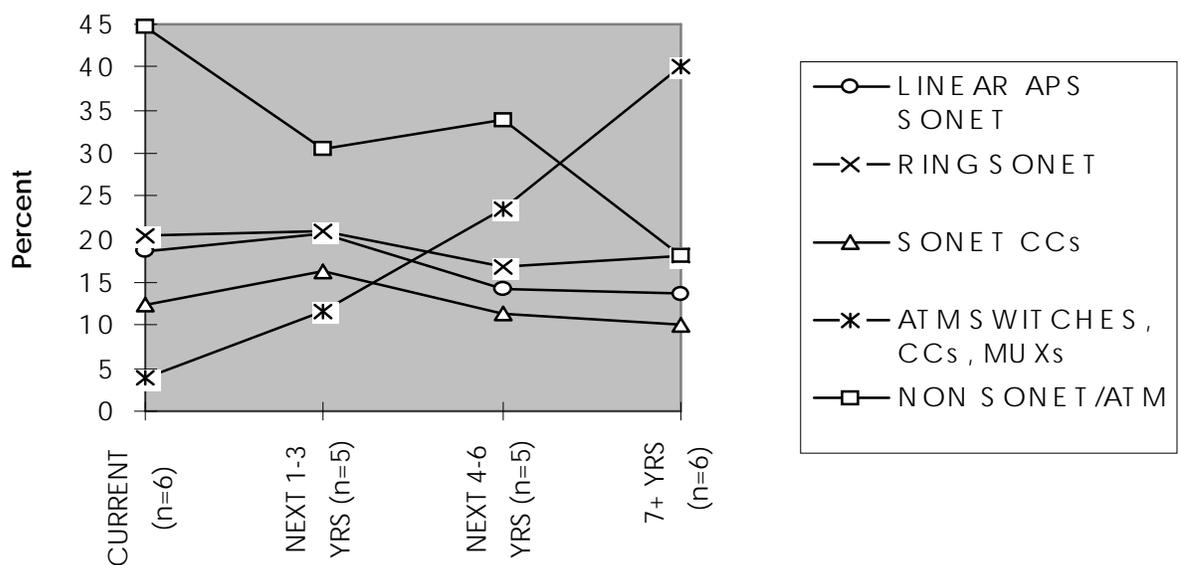- Cross-connect restoration software applicable to SONET interfaces

FAILURE MODES

- Definition from T1A1 TR 24: Survivability
  - ability to maintain or restore acceptable level of performance
  - prevention of service outages by applying preventive techniques
- A SONET ring cannot restore a fiber cut if the fiber is not physically diverse
- Human error can cause significant failures
- At SONET's higher bit rates, multiple failure events cause larger outages
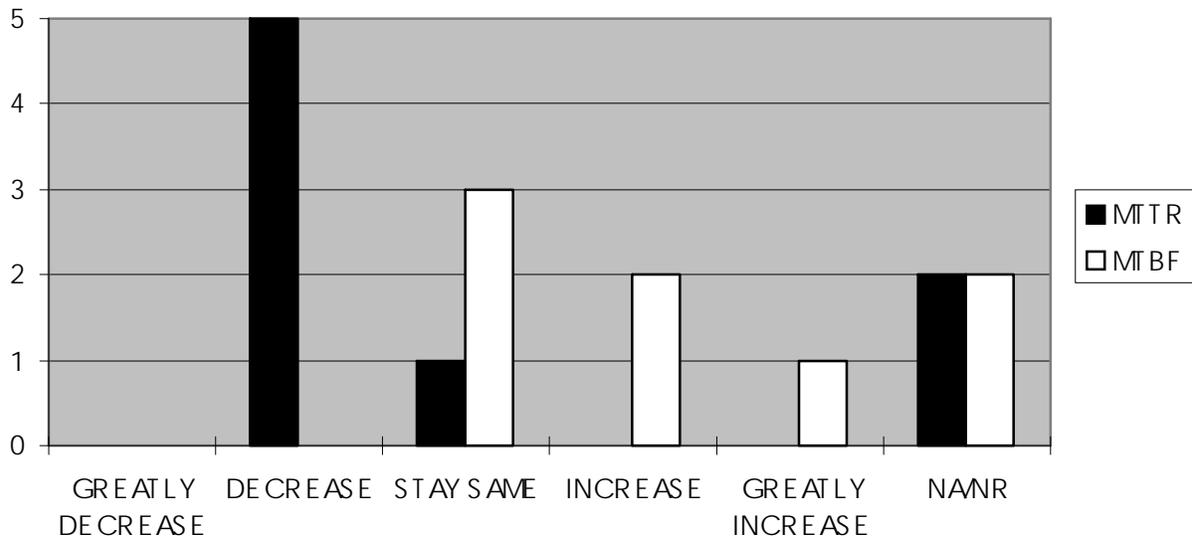
SUMMARY OF MANUFACTURER RESPONSE ANALYSIS

- ## Manufacturer revenue prognosis for next 7 years:
  - Non-SONET revenue decreasing
  - SONET revenue relatively flat
  - ATM revenue increasing
- ## Majority of manufacturers support restoration
- ## Manufacturers expect:
  - MTBF to Increase
  - MTTR to Decrease
  - Hence overall Availability will increase

Average Projected Revenue Mix

SONET/ATM MTTR & MTBF Expectations

Legend:
- MTTR (black)
- MTBF (white)

Categories: GREATLY DECREASE, DECREASE, STAY SAME, INCREASE, GREATLY INCREASE, NA/NR

Track Unsuccessful SONET Switchovers? (n=16)

NO 38%
YES 62%

Unsuccessful SONET Switchovers Per Year
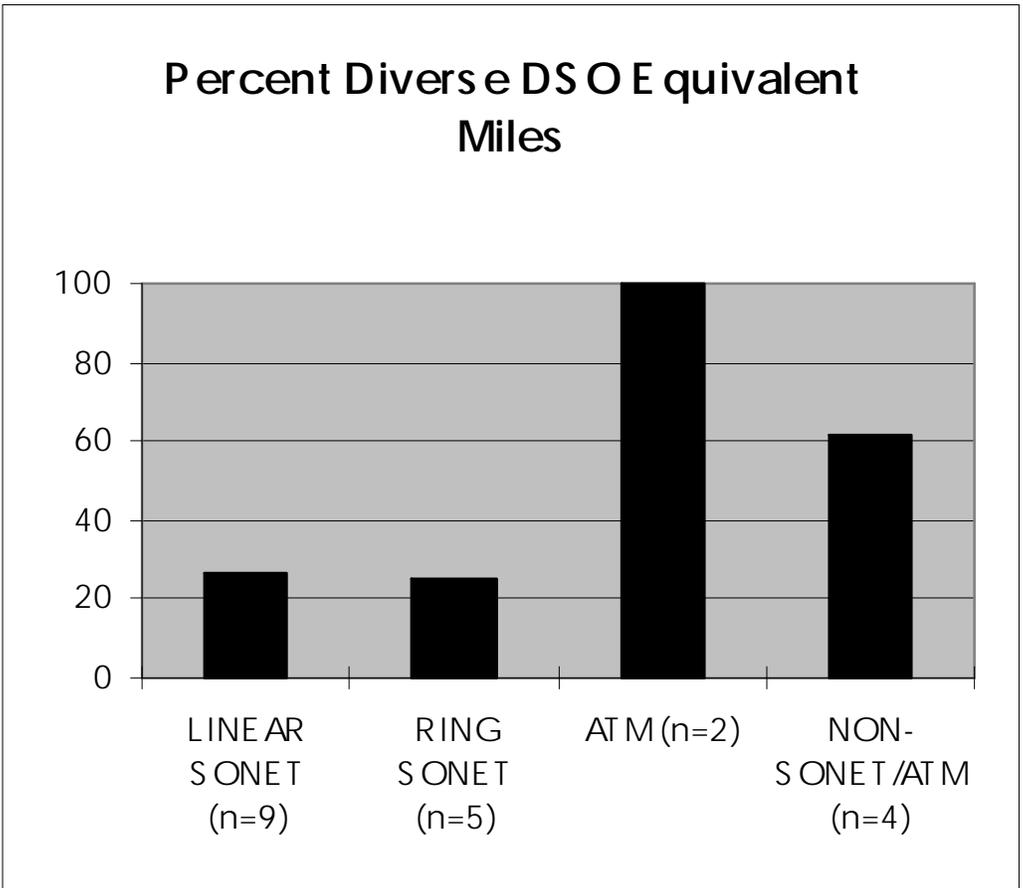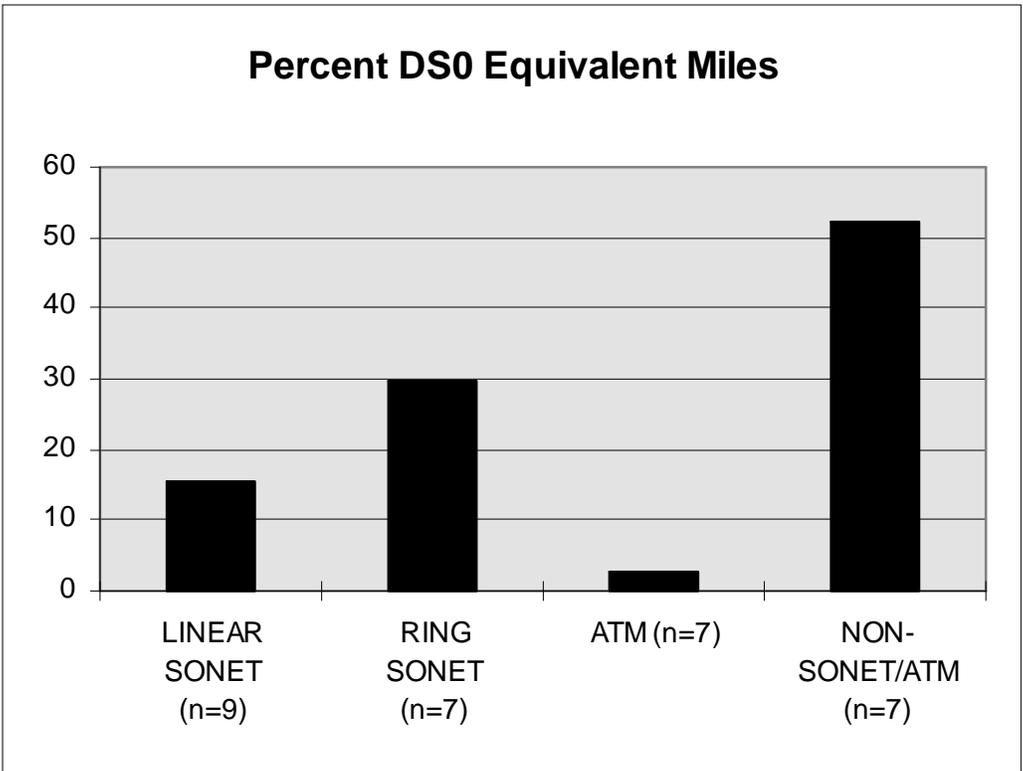

Responses vs. Number of Switchovers (0, 1, 2.5, NR)
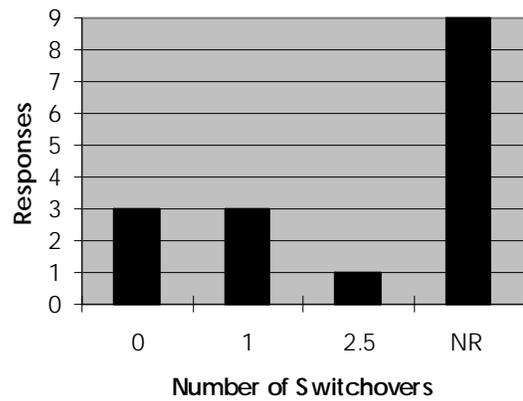
CARRIER RESPONSE ANALYSIS

- Most carriers utilize Linear SONET & SONET Rings in key services today
- Majority of carriers plan to use SONET/ATM technologies within 3 years
- Majority of carriers do not consider a 60ms SONET Ring switchover an outage
- Approximately 60% of carriers track unsuccessful SONET ring switchovers
  - Of those who do track them, and reported their experience, there were less than 1 unsuccessful switchovers per year
- Carrier ATM Survivability Plans were:
  - Physical Port Protection Switching
  - Logical Path Protection Switching

Percent DS0 Equivalent Miles

A bar chart titled "Percent DS0 Equivalent Miles" with a y-axis ranging from 0 to 60. The bars represent:
- LINEAR SONET (n=9): approximately 15.5
- RING SONET (n=7): approximately 30
- ATM (n=7): approximately 2.5
- NON-SONET/ATM (n=7): approximately 52.5

Percent Diverse DS0 Equivalent Miles

A bar chart titled "Percent Diverse DS0 Equivalent Miles" with a y-axis ranging from 0 to 100. The bars represent:
- LINEAR SONET (n=9): approximately 26
- RING SONET (n=5): approximately 25
- ATM (n=2): approximately 100
- NON-SONET/ATM (n=4): approximately 62

RECOMMENDATIONS

- Adequacy of FCC Reporting Requirements
- Constraints of T1X1.5 SONET ring specifications
- Operations-oriented recommendations
- Focus on end-to-end reliability, not only within one carrier, but on carrier interconnection

RECOMMENDATIONS

- Focus should be on availability, not only reliability
  – Reliability is a measure of how often failures occur
  – Availability is what percentage of time service is provided
- Consider extension of failure mode tracking and analysis to the case of multiple failures
- ATM Survivability techniques not standardized,
  – Given the significant carrier plans to provide key services over ATM, industry and standards (T1, ITU, ATM Forum) should standardize survivable ATM