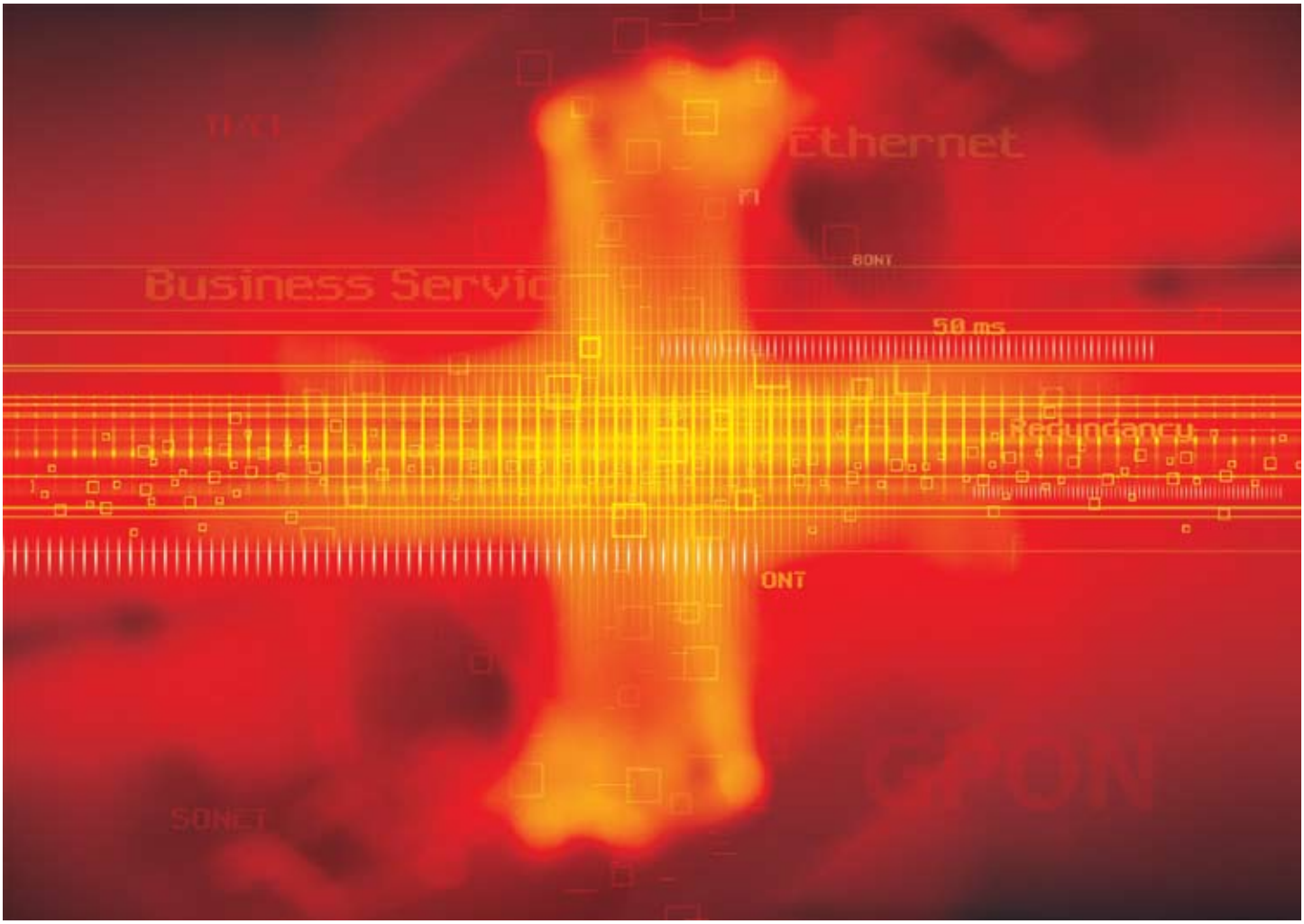
THE POSSIBILITIES ARE INFINITE FUJITSU

Business Class Services over a GPON Network



Introduction

Typically, businesses are served over a protected network with tight tolerances of parameters such as jitter and wander. A GPON network is an attractive way to deliver residential services because it is usually deployed in an unprotected mode, which makes it less expensive. A GPON network can provide the reliability and performance expected for business services if it is carefully designed from the outset.

Many neighborhoods consist of a mixture of residential homes and small businesses, where the businesses are interspersed with the residential homes. A GPON network can easily provide an unprotected but economical fiber drop to homes for residential services such as high-speed Internet access or IPTV services. On the other hand, businesses require redundancy for high reliability, and they are willing to pay a premium for their DS1 or DS3 service. The FSAN Group's G.984 specification allows for several types of redundancy within the network. However, this specification doesn't provide for the network interactions needed to use this redundancy in an efficient manner.

SONET requires a protection switch to take place within 50 ms of a fault condition for minimal impact to services. A GPON network providing business services should also be required to switch within a 50 ms window. This is a difficult, but achievable requirement if the network is designed accordingly. Consideration for switching between OLT cards and between ONT fiber ports is a critical part of this reliable network.

Another consideration for network planners is how to adequately deliver DS1 or E1 circuits without introducing unwanted jitter or wander into the network, which could cause slips and other unwanted events that lead to a less reliable service.

This paper addresses how to simultaneously provide a reliable GPON network for business service and a cost-effective GPON network for residential service. The paper addresses protection mechanisms, DS1/E1 mapping into GPON GEM strategies, and timing and synchronization requirements for providing reliable business services over a GPON network. It also covers various topology methods for providing redundant equipment and facilities for business services, and provides a summary of what some of the economic tradeoffs might be for such a network.

Background for Business Services

Revenue from business class services makes up a large percentage of the annual revenue of the average carrier. However, there are many more residential subscribers than business subscribers in a general service population. Although the ratio of business customers to residential customers may be small, the ratio of business revenue to residential revenue is about the same. Carriers consider these business customers a vital market, and servicing, maintaining, and retaining these customers is of the utmost importance.

Small businesses geographically interspersed within residential neighborhoods might be located in a strip mall in a neighborhood, next to the local gas station or in a residential home office. These are not Fortune 500 companies or Fortune 2000 customers. They are just small businesses located in a neighborhood that might only have a single T1/E1 or ADSL line for broadband service.

As most residential customers are generally aware, the telephony or ADSL line that is run to their homes is normally an unprotected service. It usually consists of a single wire pair that is run from the subscriber's location to their serving CO. If a neighbor decides to put up a fence next to a property in the easement area and accidentally sinks a fence pole that cuts the telephony cable, their service goes down. In contrast, business service tends to be protected. It is a higher revenue generator, so the carriers try to make the business services as resilient as possible. Increasing resiliency could mean running a redundant cable to the business premises, or just having a higher standard or specification for service. In delivering T1/E1 service to a customer, the carriers typically have a difficult set of specifications with which the T1/E1 needs to conform. For instance, the T1 needs to meet the specifications of GR-312-CORE and T1.403 for timing, jitter, and wander. It also needs to be able to be tested and monitored. These T1/E1 services can be synchronous or asynchronous to the network, and the business network needs to be able to accommodate either type without any degradation of service.

The Problem – Supporting Business services with PON

The large carriers are in the process of deploying fiber much deeper into their access networks than they have ever previously done. They are primarily targeting residential customers to combat the escalating MSO threat for voice, video and data services (i.e. triple play services) to residential subscribers. Carriers need to provide an economical method (i.e., unprotected) for deploying fiber deep within their networks to residential subscribers, and they also need to be able to provide business class services (i.e., protected) over this same network to serve business subscribers located in the same neighborhood. Alternatively, they could provide a separate network specifically for business customers, but this solution would prove to be very expensive relative to the revenue generated. The dilemma that the carriers face is how to provide an economical, unprotected service for residential customers, and a resilient, protected, yet economical network for business customers from the same basic network.

The Solution – GPON Topologies

At first glance, it would seem that trying to provide both an economical residential and resilient business service from the same network is an impossible task. However, this is not the case with FSAN protected networks.

FSAN has defined four types of protection topologies that offer varying degrees of protection coverage that will be individually considered for their protection coverage and approximate cost.

In order to study these elements, the access network needs to be considered. There are five basic elements that can be protected within the PON network in the first three protection schemes, and an additional element in the fourth protection scheme. These elements are shown in Figure 1 and are listed below:

- The OLT PON Port
- The F1 Facility (from the CO to the splitter)
- The Passive Optical Splitter
- The F2 Facility (from the splitter to the customer premises)
- The ONT PON Port

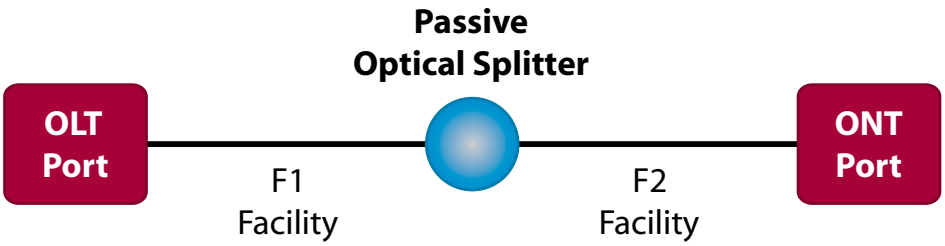


Figure 1: Protection Scheme Topologies for Types A, B, and C

The protection scheme for Type D has two additional elements: another splitter and another fiber drop between the two splitters (F1.5 Facility) as shown in Figure 2.

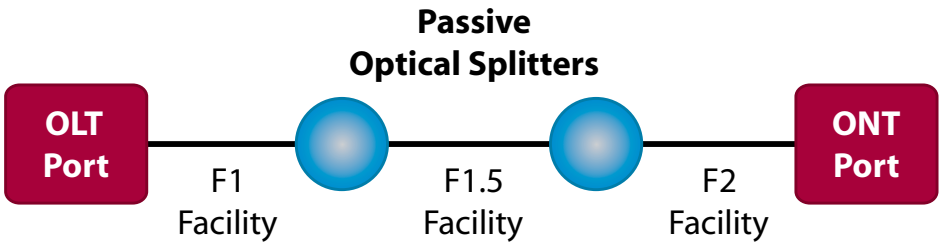


Figure 2: Protection Scheme Topology for Type D

A fully protected network would have each element protected by a redundant element. In most residential applications, none of the elements are protected. The protection coverage calculation is simply based on the number of elements that are protected as compared to the total number of elements in the network. For instance, if the network consists of five different elements, then 40% coverage would have two of the five elements protected.

In the cost analysis, the assumption is that a BONT will be equipped with two separate fiber ports such that each fiber port is completely independent. It also assumes that an SFONT will consist of a single fiber port with no redundancy.

The basic assumptions for the costs of the protection are as follows:

- The fiber ports for the ONT are each $100, which does not include the rest of the cost of the ONT.
- The F2 fiber cost is $300 each.
- The splitter cost is $1000, but shared amongst 32 users.
- The F1 fiber cost is $500, but shared amongst 32 users.
- The OLT port cost is $1500, but shared amongst 32 users.
- In the Type D case, the 1x2 splitter is $300, but shared amongst 32 users.
- In the Type D case, the F1.5 fiber cost is $300, but shared amongst 32 users.

These costs can be argued up or down, but the primary point here is to find a relative cost for the different types of ONTs and different protection topologies.

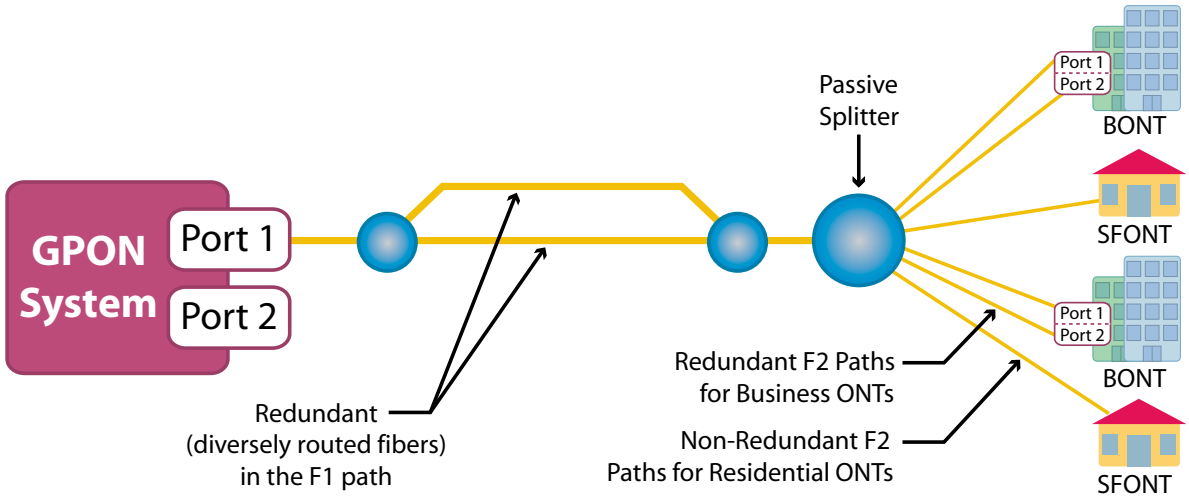


Figure 3: Type A Protection Scheme

In the diagram shown in Figure 3 (which is the Type A redundancy scheme), the F1 facility is the only portion of the network that is redundant. This assumes that the F1 facilities are diversely routed such that if a "backhoe" failure occurs in the F1 portion of the network, it will not be able to cut both F1 cables.

As Table 1 shows, a BONT with two fiber ports can have about 60% protection coverage in a Type A protection scheme since the carrier can run redundant cables from the splitter to the BONT. These cables again should be diversely routed for "backhoe" protection. This table also shows that the residential ONT has 20% protection coverage in a type A configuration.

The approximate costs of the relative protection mechanism are shown in Table 1, with the BONT costs running about $909, while the residential ONT costs run about $509. Thus the BONT costs nearly twice as much as the SFONT in terms of its protection costs, but it is only 60% protected.

Type A - Protection				
Type of ONT	**Business ONTs**		**Residential ONTs**	
Element	**Approx. Cost/User**	**Protection**	**Approx. Cost/User**	**Protection**
ONT Port Primary	$100.00	P	$100.00	U
ONT Port Protect	$100.00			
F2 Fiber Primary	$300.00	P	$300.00	U
F2 Fiber Protect	$300.00			
Splitter	$31.25	U	$31.25	U
F1 Fiber Primary	$15.63	P	$15.63	P
F1 Fiber Protect	$15.63		$15.63	
OLT Port	$46.88	U	$46.88	U
Total	**$909.38**	**60%**	**$509.38**	**20%**

Table 1: Type A Protection Coverage and Approximate Cost per User

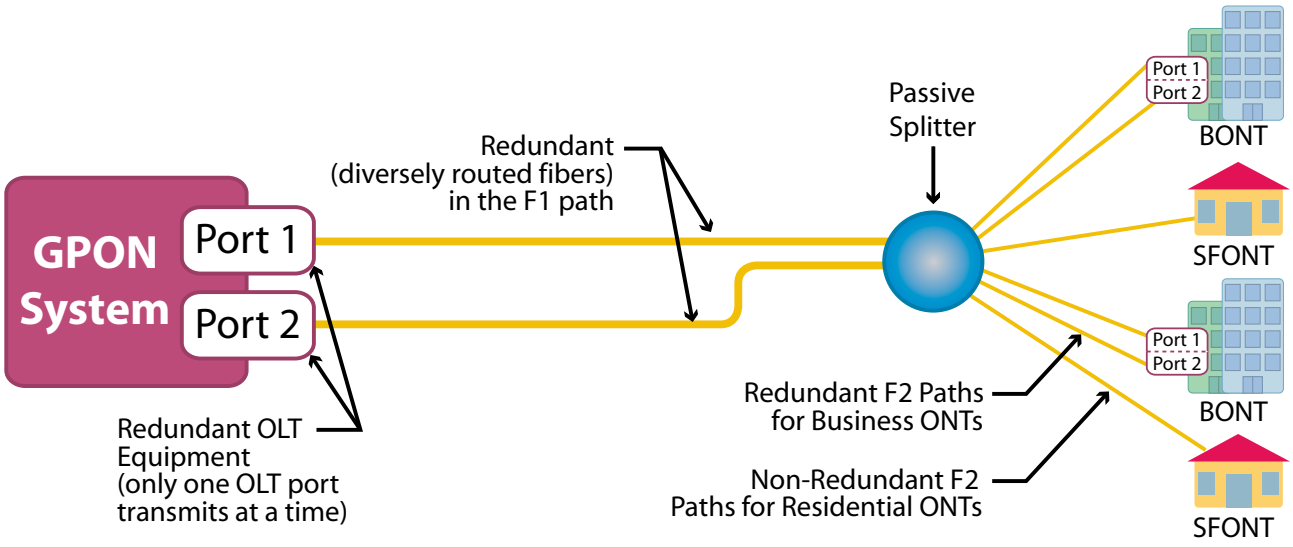


Figure 4: Type B Protection Scheme

In the diagram shown in Figure 4 (which is the Type B method), both the OLT ports and the F1 facilities are protected, however the splitter is not protected. The splitter is a 2x32 splitter, meaning that it has two ports on the network side but 32 ports on the access side. Each of the OLT ports is redundant, but only one of them can transmit at a time. However, they can both receive data at the same time. The redundant OLT ports and the F1 facilities protect all of the ONTs (residential and business), though the BONTs continue to have the F2 protection and ONT port protection as well.

As demonstrated in Table 2, the BONT has about 80% protection coverage while the residential ONT has 40% protection. The BONT costs continue to be nearly twice the cost of the residential ONT.

Type B - Protection				
Type of ONT	**Business ONTs**		**Residential ONTs**	
Element	**Approx. Cost/User**	**Protection**	**Approx. Cost/User**	**Protection**
ONT Port Primary	$100.00	P	$100.00	U
ONT Port Protect	$100.00			
F2 Fiber Primary	$300.00	P	$300.00	U
F2 Fiber Protect	$300.00			
Splitter	$31.25	U	$31.25	U
F1 Fiber Primary	$15.63	P	$15.63	P
F1 Fiber Protect	$15.63		$15.63	
OLT Port Primary	$46.88	P	$46.88	P
OLT Port Protect	$46.88		$46.88	
Total	**$956.25**	**80%**	**$556.25**	**40%**

Table 2: Type B Protection Coverage and Approximate Cost per User

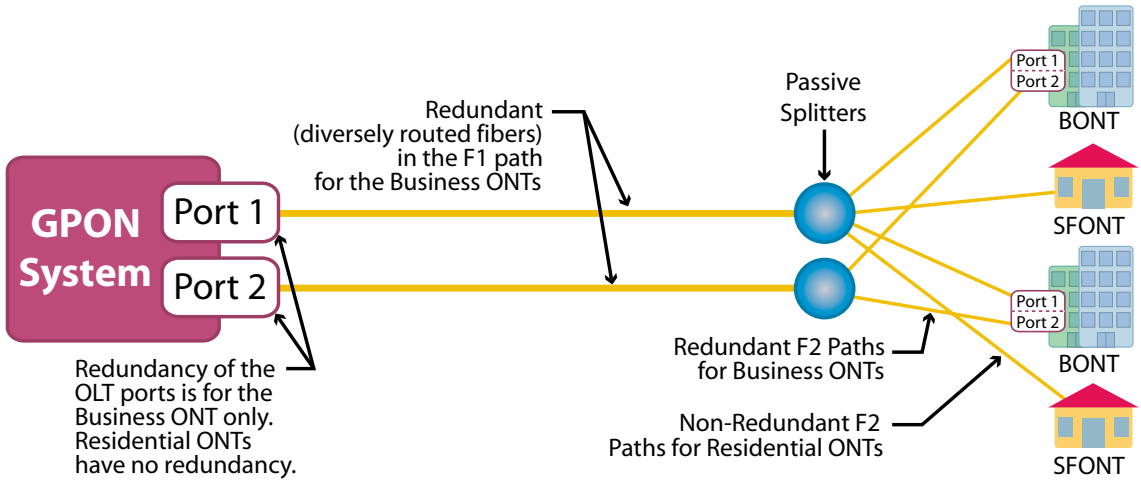


Figure 5: Type C Redundancy Scheme

In the diagram shown in Figure 5 (which is the Type C protection method), there are two splitters so that this element can also be protected. This solution provides 100% protection coverage of the BONTs, however, this is actually a poorer solution for the residential ONTs. The reason is that if a protection switch occurs at the OLT port, all of the residential subscribers lose service since their service will not be switched along with the OLT port. Conversely, this is an excellent method of protection and provides 100% coverage for all ONTs that have dual fiber feeds. This topology provides 100% coverage for only about $20 more per BONT over the Type B protection, as shown in Table 3.

Type C - Protection				
Type of ONT	**Business ONTs**		**Residential ONTs**	
Element	**Approx. Cost/User**	**Protection**	**Approx. Cost/User**	**Protection**
ONT Port Primary	$100.00	P	$100.00	U
ONT Port Protect	$100.00			
F2 Fiber Primary	$300.00	P	$300.00	U
F2 Fiber Protect	$300.00			
Splitter Primary	$31.25	P	$31.25	P
Splitter Protect	$31.25		$31.25	
F1 Fiber Primary	$15.63	P	$15.63	P
F1 Fiber Protect	$15.63		$15.63	
OLT Port Primary	$46.88	P	$46.88	P
OLT Port Protect	$46.88		$46.88	
Total	**$987.50**	**100%**	**$587.50**	**60%**

Table 3: Type C Protection Coverage and Approximate Cost per User

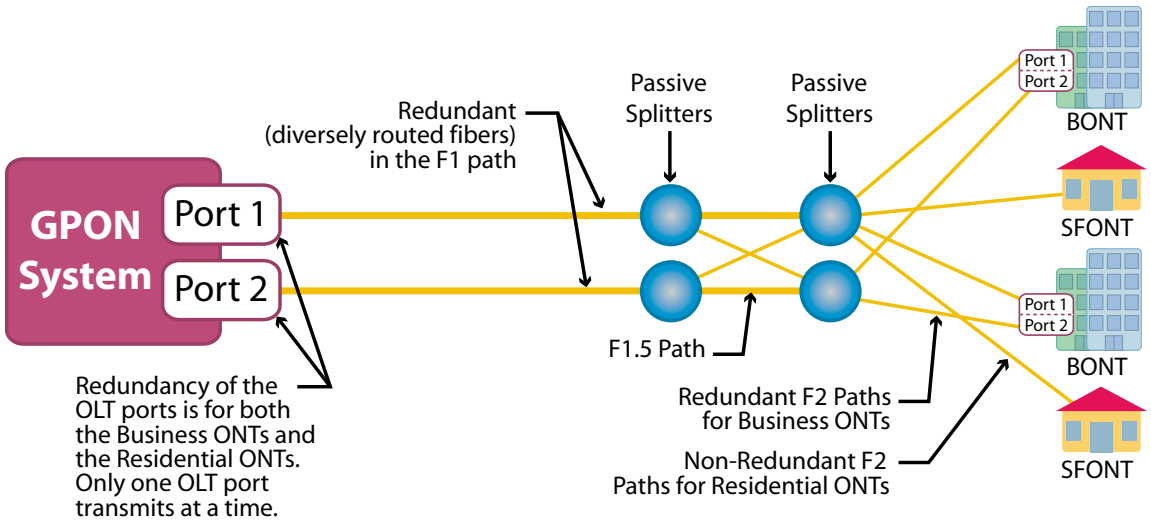


Figure 6: Type D Redundancy Scheme

The diagram shown in Figure 6 is the Type D protection method. This example provides the maximum protection for both the business customer and the residential customer. The idea with this topology is that it provides a path from either OLT port to the BONT and to the residential ONT. If a protection switch occurs at the OLT port, the residential customers with only a single fiber feed will continue to be provided service from the redundant OLT. Of course the SFONT is still exposed on the F2 fiber drop and the ONT port, but this method is the maximum amount of protection with a residential coverage of 71% and business coverage of 100%. The approximate protection costs are $600 and $1000 respectively for the residential and BONTs, as shown in Table 4.

Type D - Protection				
Type of ONT	**Business ONTs**		**Residential ONTs**	
Element	**Approx. Cost/User**	**Protection**	**Approx. Cost/User**	**Protection**
ONT Port Primary	$100.00	P	$100.00	U
ONT Port Protect	$100.00			
F2 Fiber Primary	$300.00	P	$300.00	U
F2 Fiber Protect	$300.00			
Splitter F2 Primary (2x32)	$31.25	P	$31.25	P
Splitter F2 Protect (2x32)	$31.25		$31.25	
F1.5 Fiber Primary	$6.25	P	$6.25	P
F1.5 Fiber Protect	$6.25		$6.25	
F1.5 Fiber Crossover Primary	$6.25	P	$6.25	P
F1.5 Fiber Crossover Protect	$6.25		$6.25	
Splitter F1 Primary (1x2)	$9.38	P	$9.38	P
Splitter F1 Protect (1x2)	$9.38		$9.38	
OLT Port Primary	$46.88	P	$46.88	P
OLT Port Protect	$46.88		$46.88	
Protection Level	**$1,000.00**	**100%**	**$600.00**	**71%**

Table 4: Type D Protection Coverage and Approximate Cost per User

As one can see from the graphs shown in Figure 7 and Figure 8, the relative protection costs do go up slightly over the four types of protection, however, the protection coverage goes up substantially higher to 100% in the BONT case and up to 71% in the SFONT case.

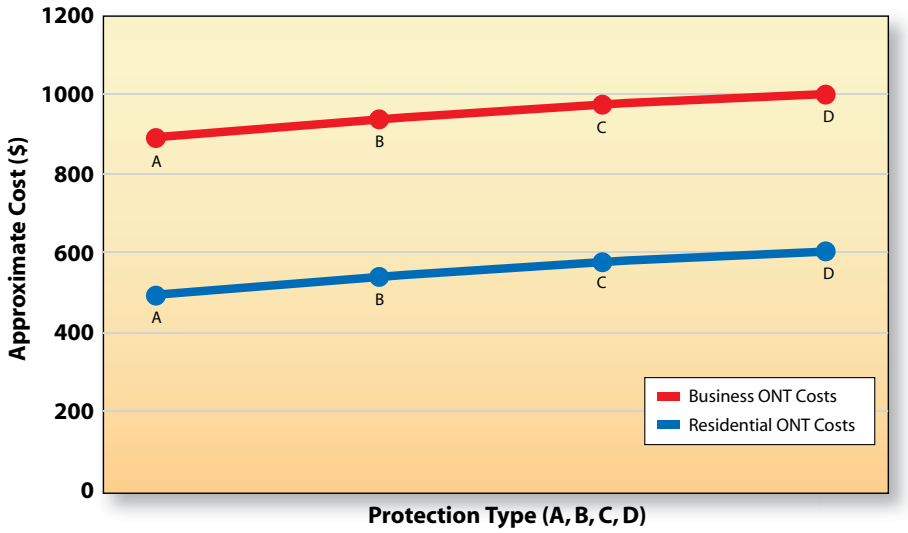


Figure 7: Approximate Protection Costs

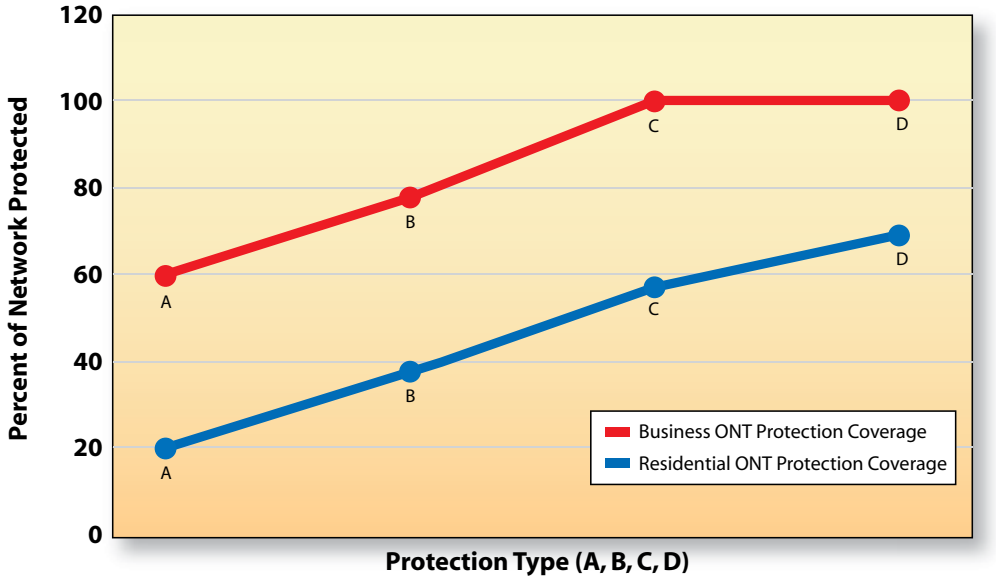


Figure 8: Protection Coverage

Switching Speeds

Another aspect of providing protection is a measure of how quickly the transition takes place from when the primary unit fails or does not receive a signal, the failure is detected, and the switch over to the secondary unit is complete. In the case of Type C redundancy, both OLT ports can be on line at the same time communicating to the redundant ports of the ONT. When a failure is detected, the secondary OLT can be put into service very quickly since the ranging has already taken place and only the payload paths need to be moved over to the redundant card. However, this redundancy switch puts the residential ONTs out of service since they do not have redundant ONT ports.

In the case of Type B or D, a switch-over requires re-ranging of the ONTs to the new OLT port, which could take about ten seconds. Initially, the ONTs are ranged to one OLT, but when the redundancy switch takes place, the ONTs are communicating to the redundant OLT port, which requires re-ranging. There may be methods of sharing the ranging distance between the primary OLT and the secondary OLT such that the convergence of ranging takes place at a faster rate, however, it could still take on the order of seconds for a complete switch-over to take place. This also assumes that the distance differential between the primary fiber path and the secondary fiber path is within the ranging error.

Network Handoffs

The handoff to the PSTN is a critical component in the complete view of the network as it has an impact on both the cost and the reliability of the network.

If a T1/E1 is to be handed off to a SONET/SDH network (Figure 9), a different approach would be optimal. This would require adapting the DS1 to a VT1.5/VT2 at the ONT and then handing this VT1.5/VT2 off to the SONET/SDH network as a VT mapped STS-1 or OC-n. This again places the adaptation burden on the BONT and not on the OLT, which in turn does not place an unnecessary cost burden on the residential subscribers.

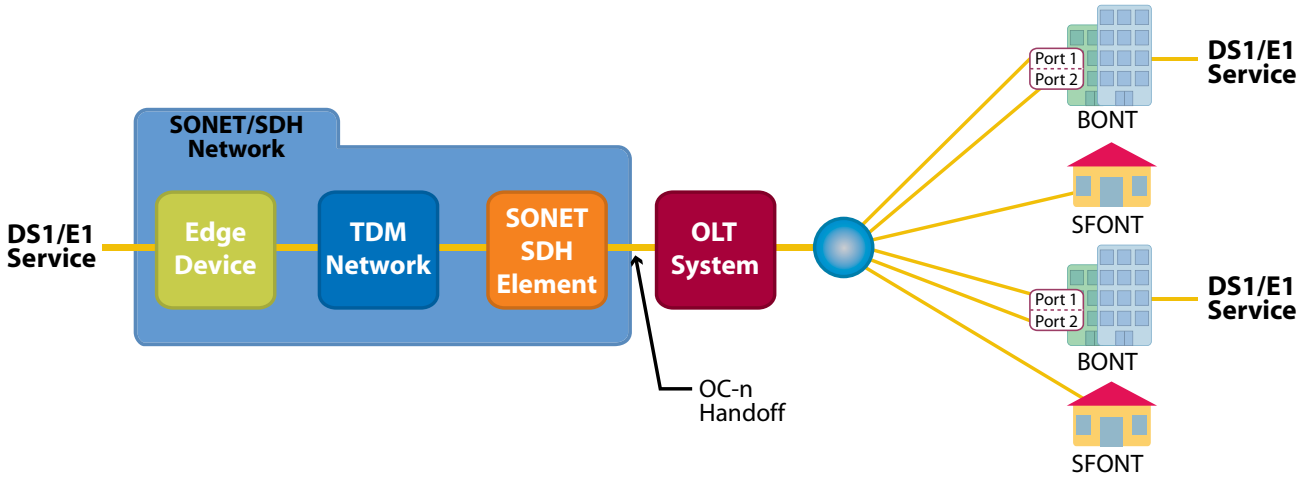


Figure 9: SONET/SDH Handoff

However, if a T1/E1 is to be transported over a packet network (Figure 10), then the most likely handoff from the PON system to the network cloud would be a circuit emulated handoff, using AAL1 or an MEF protocol. If the DS1/E1 is adapted to the AAL1 or MEF CES format at the ONT, then it should pass through the OLT transparently. This puts the adaptation burden of the cost at the business ONT, but does not burden the OLT with any adaptation costs.

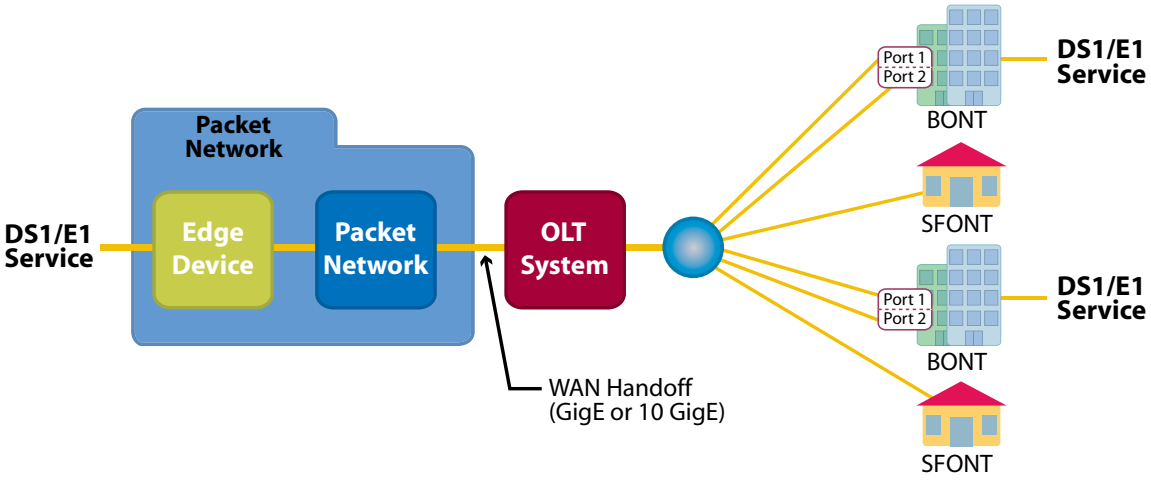


Figure 10: Packet Network Handoff

The worst situation would be to transport the DS1/E1 from the ONT to the OLT, recover the DS1/E1 at the OLT, and then re-adapt it to a second type of handoff. This would add adaptation costs to the ONT and OLT, and also degrade the T1 with additional jitter due to the recovery process. It would also require the OLT be pre-designed to support a maximum number of DS1s/E1s, and once this limit was reached, it would not be able to support any additional DS1s/E1s. Another drawback to this type of design is that it would require the circuitry power and cost to support the DS1s/E1s on the OLT regardless of whether or not the DS1s/E1s were being used or not.

To ensure that business services are optimized for cost and performance, the adaptation should occur as close to the edge as possible. Otherwise, jitter and wander tend to accumulate per every adaptation, which results in degradation of the service.

DS1Structure Agnostic

* Adaptation Byte count depends on the Adaptation type.

VT Structure Locked, (SPE Indicated) DS1 Agnostic

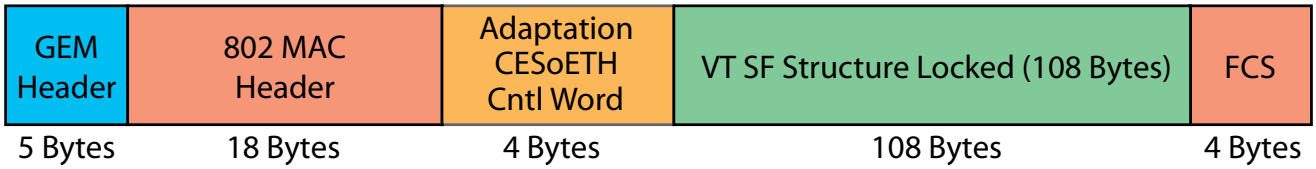


Figure 11: Adaptation Suggestions for DS1s

Two different adaptation-mapping structures are shown in Figure 11: one for DS1s over a packet-based network as shown in Figure 10, and a second to support VTs over a SONET/SDH network as shown in Figure 9. These methods are based on the following premises:

- Ethernet encapsulation and the MEF CESoETH header are used;
- BONTs that support DS1 service are configurable to support at least the two encapsulation methods;
- Both methods above are DS1/E1 agnostic and support synchronous or asynchronous DS1/E1s;
- OLTs are simple and used for handoff to the transport network. Complexity is added at the BONT (pay as you go)
  - ONTs should use VT encapsulation if destined for the SONET/SDH transport network
  - ONTs should use DS1 agnostic pseudowire encapsulation if destined for packet transport

Summary

There are several network design and system design methods that can deliver a true carrier-class business service to the carriers' most valued customers, while at the same time providing an economical but reliable service to residential customers.

Concerning the network design methods, the optimum protection topology for switching speed would be method Type C. However, due to its drawback of losing service for unprotected ONTs, it should only be used on a network that has protected ONT ports such as those found on BONTs. The optimum protection topology based on the maximum level of protection would be Type D, particularly if the ONTs being served are of the mixed type (i.e., protected and unprotected ONT ports).

From a system design perspective, there are certain places where network adaptation can take place that can bring both economic and performance benefits. These areas reside at the very edge of the network, typically in a BONT so that they do not burden the cost of the residential ONTs or the OLT.

If designed properly, these methods can bring added value to the carriers so that they in turn can bring value to their residential and business customers.

Acronym	Descriptor
AAL1	ATM Adaptation Layer
ADSL	Assymetric Digital Subscriber Line
ATM	Asynchronous Transfer Mode
BONT	Business Optical Network Terminal
CESoETH	Circuit Emulation Service over Ethernet
CO	Central Office
FSAN	Full Service Access Network
GEM	Government, Education, and Military
GPON	Gigabit Passive Optical Network
IPTV	Internet Protocol Television
MEF	Metro Ethernet Forum
MSO	Multiple System Operator
OLT	Optical Line Terminal
ONT	Optical Network Terminal
PON	Passive Optical Network
PSTN	Public Switched Telephone Network
SDH	Synchronous Digital Hierarchy
SF	Switch Fabric
SFONT	Single-Family Optical Network Terminal
SONET	Synchronous Optical Network
VT	Virtual Tributary

FUJITSU NETWORK COMMUNICATIONS INC.
2801 Telecom Parkway, Richardson, Texas 75082-3515
Telephone: (972) 690-6000
(800) 777-FAST (U.S.)
us.fujitsu.com/telecom