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Passive optical network protection considerations

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Supplement 51 to ITU-T G-series Recommendations

Passive optical network protection considerations

Summary

Passive optical networks (PONs) can generally be considered point-to-multipoint networks, much like wireless networks such as wireless fidelity (Wi-Fi), 2G–4G or the hybrid fibre coax (HFC) networks used by multiple system operators. Redundancy is generally not fundamental in these networks as contrasted with ring-based topologies.

Nonetheless, there are services such as business services, mobile backhaul and high-density residential services, which may justify the addition of PON redundancy and protection switching.

Recommendation ITU-T G.984.1 outlines several topologies for achieving redundancy; these have been named type A, type B, type C and type D. Since the publication of ITU-T G.984.1, many other studies of various aspects of PON availability, redundancy and switching have been made available.

The ITU-T G.987 series, ITU-T G.989 series and ITU-T G.9807.1 describe the 10-Gigabit-capable passive optical network (XG-PON), the 40-Gigabit-capable passive optical network (NG-PON2) and the 10-Gigabit-capable symmetric passive optical network (XGS-PON) systems. Each of these further describe protection aspects of those systems. In particular, the details of automatic protection switching in type B has been more fully worked out.

This Supplement collects this information and, guided by input from operators, distils it into use cases and methods that are recommended for adding redundancy and increasing the reliability of PON networks.

History

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The World Telecommunication Standardization Assembly (WTSA), which meets every four years, establishes the topics for study by the ITU-T study groups which, in turn, produce Recommendations on these topics.

The approval of ITU-T Recommendations is covered by the procedure laid down in WTSA Resolution 1.

In some areas of information technology which fall within ITU-T's purview, the necessary standards are prepared on a collaborative basis with ISO and IEC.

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Supplement 51 to ITU-T G-series Recommendations

Passive optical network protection considerations

1 Scope

Passive optical networks (PONs) are point-to-multipoint networks, much like wireless networks such as wireless fidelity (Wi-Fi), 2G–4G or the hybrid fibre coax (HFC) networks used by multiple system operators. Redundancy is generally not fundamental in these networks when compared to ring-based topologies.

Nonetheless, there are services such as business services, mobile backhaul and high-density residential services that may justify the addition of PON redundancy and protection switching.

[b-ITU-T G.984.1] outlines several topologies for achieving redundancy; these have been named type A, type B, type C and type D. Since the publication of [b-ITU-T G.984.1], many other studies of various aspects of PON availability, redundancy and switching have been made available.

This Supplement collects this information and, guided by input from operators, distils it into use cases and methods that are recommended for adding redundancy and increasing the reliability of PON networks.

2 Abbreviations and acronyms

This Supplement uses the following abbreviations and acronyms:

2G–4G	second Generation to fourth Generation
10G-EPON	10-Gigabit Ethernet Passive Optical Network
BA	Bandwidth Allocation
BNG	Broadband Network Gateway
BW	Bandwidth
CCM	Continuity Check Message
EMS	Element Management System
E-PON	Ethernet Passive Optical Network
EqD	Equalization Delay
FIT	Failure in Time
FTTH	Fibre to the Home
FWI	Forced Wakeup Indicator
G-PON	Gigabit-capable Passive Optical Network
HFC	Hybrid Fibre Coax
IGMP	Internet Group Management Protocol
ISDN	Integrated Services Digital Network
LAG	Link Aggregation
LOF	Loss of Frame
LOS	Loss of Signal
LSB	Least Significant Bit

MAC	Media Access Control
MEG	Maintenance Entity Group
MEP	Maintenance entity group Endpoint
MTBF	Mean Time Between Failures
MTTR	Mean Time to Repair
NG-PON2	40-Gigabit-capable Passive Optical Network
NMS	Network Management System
OAM	Operations, Administration and Maintenance
OAN	Optical Access Network
ODN	Optical Distribution Network
OLT	Optical Line Terminal
ONU	Optical Network Unit
PLOAM	Physical Layer Operations, Administration and Maintenance
PON	Passive Optical Network
POTS	Plain Old Telephone Service
QoS	Quality of Service
RE	Reach Extender
RTD	Round-Trip Delay
RTT	Round-Trip Time
SDi	Signal Degrade
SFi	Signal Fail
SLA	Service Level Agreement
SME	Small to Medium-sized Enterprises
SNI	Server Node Interface
S-VID	Service VLAN Identifier
TDM	Time Division Multiplex
TDMA	Time Division Multiple Access
UNI	User Network Interface
VID	VLAN Identifier
VLAN	Virtual Local Area Network
WDM	Wavelength Division Multiplexing
Wi-Fi	Wireless Fidelity
XG-PON	10-Gigabit-capable Passive Optical Network
XGS-PON	10-Gigabit-capable Symmetric Passive Optical Network

3 Background – Fibre protection

Optical access networks (OANs) are now delivering multimedia services including data, voice and video. OANs also serve as mobile backhaul connecting wireless towers to metro or core networks. Although the physical media in the last (or first) mile could be different from fibre, OANs are an integral part of any broadband access network. Most OANs use passive optical network (PON) architectures.

As society moves towards 'everything in cloud', 'everything on a click', 'remote working', 'global collaboration', 'e-business' and 'social networking', a single network failure can disrupt services of hundreds of users and have a cascading effect. Users will find it unacceptable because their survival and well-being are now highly dependent on the health of the access networks. The access network will be considered an essential service. Thus, to meet service level agreements (SLAs) and guarantee the appropriate level of connection availability, fault management within any type of PON becomes more significant for reliable service delivery and business continuance. Failure of any network component will interrupt the service resulting in a significant loss of revenues. Service subscribers expect the quality of service (QoS) to be at least at the same level as that provided by the copper-based plant. Currently, PONs are mostly poorly protected or not protected at all. Fibre cuts are not the only issue. Failure may occur in the optical line terminal (OLT), optical network unit (ONU) power splitter or optical amplifier, if employed.

3.1 PON system components – Failure rates

There have been several reports on failure rates and time to repair for PON system components. Failure rates differ widely and depend on geography, environment, assumptions and component design, at a minimum. Table 1 is a compilation of the component failure rates taken from these references and has references to the various sources used for failure rates and times to repair for the different elements of the network.

3.2 Failures in time and mean time between failures

The failure of some network elements has more impact on services than others. For example, ONU failure or distribution fibre cuts affects only one user. But a failure of OLT, feeder fibre or a remote node can shut down the entire PON. Mean time to repair (MTTR) will also be different for different network elements. Table 1 summarizes some statistical data relating to unavailability of the network due to failure of network components. Here, the FIT column lists the failure frequency over 10^9 h and MTTR applies to each failure.

Unavailability is defined as the probability that the equipment, service or fibre is unavailable at any time and can be defined mathematically as:

Network unavailability due to a component failure = FIT $\times$ MTTR $\times 10^{-9}$

Another measure of failure rates is the mean time between failures (MTBF). This is the average time between failures for an MTBF (h) = 10^9 /FIT.

FIT versus MTBF will be used for the rest of this Supplement.

Table 1 – Survey of failure rates and repair times for PON components in published literature

Equipment	Reference	FIT	MTTR (h)	Unavailability
OLT	[b-Alcoa]	NA	NA	NA
	[b-Chen, 2008]	2 500	4	1×10^{-5}
	[b-Hajduczenia]	7 000	5	3.5×10^{-5}
	[b-Chen, 2010], [b-Tsubokawa]	NA	NA	NA
ONU	[b-Alcoa]	NA	NA	NA
	[b-Chen, 2008]	256	24	6.1×10^{-6}
	[b-Hajduczenia]	2 500	12	3×10^{-5}
	[b-Chen, 2010], [b-Tsubokawa]	NA	NA	NA
Deployed optical fibre cable (Note 1)	[b-Alcoa]	10/km–250/km (Note 2)	NA	NA
	[b-Chen, 2008]	NA	NA	NA
	[b-Hajduczenia]	200/km	14	2.8×10^{-6}
	[b-Chen, 2010], [b-Tsubokawa]	18/km	6	6×10^{-11}
Splitter	[b-Alcoa]	NA	NA	NA
	[b-Chen, 2008]	50–120	24	1.2×10^{-7} to 2.9×10^{-6}
	[b-Hajduczenia]	200	12	2.4×10^{-6} /km
	[b-Chen, 2010], [b-Tsubokawa]	50–100	6	3×10^{-7} to 6×10^{-7}
Optical switch	[b-Alcoa]	NA	NA	NA
	[b-Chen, 2008]	200	14	4.8×10^{-6}
	[b-Hajduczenia]	NA	NA	NA
	[b-Chen, 2010], [b-Tsubokawa]	NA	NA	NA

NOTE 1 – [b-GR-418] requires no more than 400 FIT/mile, equal to 250 FIT/km. Also, the MTTR for [b-GR-418] is 6 h not 24 h.

NOTE 2 – [b-Alcoa] distinguished between aerial and buried fibre. Aerial = 10 FIT/km, buried 250 FIT/km. The 250 FIT/km may be a result of poor control of utility digging policies; it should be seen as an upper bound (as evidenced by the fact that [b-GR-418] has a requirement of less than 250 FIT/km).

NOTE 3 – Some data shown are based on Table 5.1 of [b-Chen, 2008], and [b-Alcoa].

4 PON protection use cases

There are many applications where PON protection will be desired or necessary. Some use cases are described here.

4.1 Large numbers of subscribers per PON line card

Larger numbers of subscribers are enabled with higher speed PONs, high density PON line cards and large split ratios due to larger link budgets (e.g., C+ optics and XG-PON extended link budgets).

There are already several large-scale PON deployments around the world based on the Ethernet passive optical network (E-PON) or Gigabit-capable passive optical network (G-PON). Efforts are under way to mature XG-PON or 10-Gigabit Ethernet passive optical network (10G-EPON) technologies cost-effectively. With their deployment, the subscriber count per PON can increase several fold. In addition, higher density PON line cards service larger subscriber counts even without increased split ratios. Since cost of protection will be shared by a large number of subscribers, PON protection will become more cost effective even as it becomes more necessary. Given these are generally residential services, “five 9s” (availability 99.999% of the time) may or may not be necessary.

4.2 Business and mobile backhaul services

Business and mobile backhaul services have higher availability requirements, normally five 9s or higher, based on SLAs. They cannot afford network outages even for a very short period, as this could have very serious negative consequences to their business. For these customers, additional costs of protection will be less important than keeping the communication working.

4.3 PON reach extenders

To bring about the cost and energy savings required for next-generation PONs to remain economically viable, there are emerging requirements from operators for node consolidation and reduction of real estate with the associated benefits of operational cost reduction. With the centralization of equipment comes a vulnerability of the network to large-scale outages in the event that a node is rendered out of service due to some catastrophic event such as fire, earthquake or flood. Such networks are likely to also have an active remote node that will employ optical amplifiers increasing the probability of failure. The very long distances allowed by reach extenders (REs) will also increase the probability that there may be a trunk fibre cut. In such networks, MTTR will also be longer.

In addition, PON REs allow higher split ratios since the split ratios will not be limited due to the link budget used for long reach. A use case with REs is shown in Figure 1.

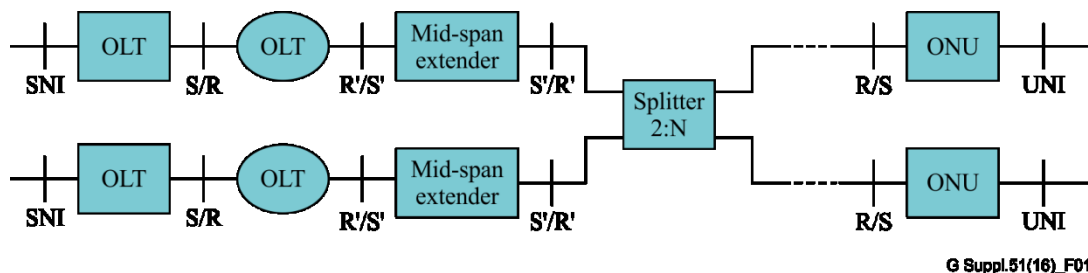


Figure 1 – Use case with reach extenders

4.4 Emergency services

Emergency services like hospitals, police, fire as well as other safety- and security-related departments require continuous communications regardless of the cost. PON protection will be very important for such subscribers.

4.5 PON maintenance

PON protection may be useful in avoiding planned maintenance outages. Often when software or hardware upgrades of an OLT (or ONT or PON) are scheduled, there is an unavoidable PON outage of seconds or minutes as a result. The operator may schedule the upgrade to take place during a so-called 'maintenance window', typically a time in the early morning where there is limited use of the PON by subscribers. This is clearly less than ideal, as there is still a service outage. Subscribers

may often be using the service even in the maintenance window. Moreover, the operator's technicians are required to perform these maintenance activities during unpopular work schedules.

PON protection has been utilized to allow near “hitless” software and hardware upgrades. The process involves initiating a manual PON protection switchover from one OLT or PON to another. In this use case, fast switchover is required as the purpose is to reduce the typical outage of seconds or minutes to fractions of a second, thereby avoiding disruption of service and allowing maintenance to proceed during normal business hours.

5 Protection architectures

There are quite a few PON protection architectures already defined in PON standards both by ITU-T and IEEE, such as type B, type B dual homing, type C, extra traffic for type C and type D to ensure network reliability and resiliency. The difference between these protection schemes depends on what is being protected: feeder fibre; feeder and drop fibres; OLT equipment; OLT and ONU equipment; or a mix and match between them. These all have different impacts on availability and cost depending on probability of fibre cuts (due to “backhoe fade” and non-human intervention, such as falling trees from snow or storm and hungry rats and monkeys), equipment MTTF, temperature swings and fibre-rich versus fibre-poor optical distribution networks (ODNs). As operators are deploying more and more subscribers on an access node, high availability and redundancy are becoming requirements.

Compared with transport networks, access networks are very cost sensitive because only a few subscribers need to share all the costs associated with the protection. Currently there is a lack of deployment of PON protection systems, largely because of cost considerations. Building redundancy into PON will make it more expensive. Any protection architecture should minimize additional cost of protection and at the same time improve network resiliency to an acceptable level. Furthermore, deployment of protection will become more cost effective and attractive if protection assets can also be used to carry over extra traffic during normal use, thus increasing the network capacity.

The ODN constitutes the most significant cost and failure of a PON system and thus any architecture deployed should minimize the cost of the ODN while providing resiliency. Some more cost-effective solutions include:

- a) use of N:1 protection where 1 OLT provides protection to N PONs (where $N > 1$) through an optical switch;
- b) use of a protection PON for extra traffic during peak times;
- c) use of protection on demand and as per the need of customers, such as software upgrades.

Which methods are most feasible depends on cost and availability. A subscriber may have an SLA requirement of five 9s (which means not more than 5.25 min failure in 1 year), but going beyond this will increase costs significantly. Operators may offer a suite of services with different levels of QoS or availability.

5.1 Type A

This protects only feeder fibre (as in Figure 2) and its usefulness depends on the ODN architecture. Two events in 2011 in New Jersey, USA: hurricane Irene and an untimely snow fall in October (when trees still had their leaves) caused serious damage to trees. Many trees fell on power and communication cables hanging on poles causing disruption of electric power and communication for several days in several thousand homes and businesses.

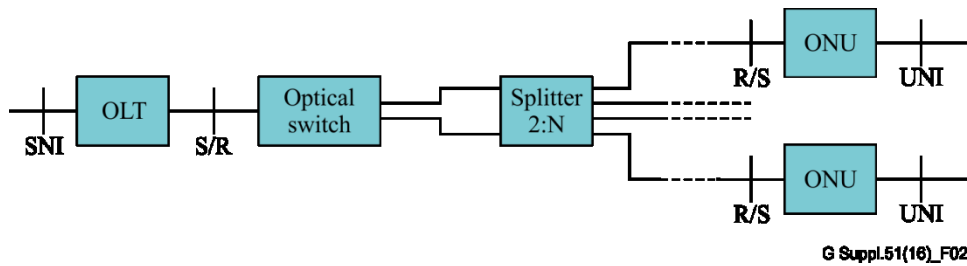


Figure 2 – Type A PON protection

If the ODN fibre is deployed underground, fibre cut or fibre damage from rats or other animals (via gnawing) are serious concerns. If fibre cables are hanging on poles, any weather storm or earthquake could inflict serious damage to the ODN. In these cases, feeder fibre protection (type A) is very useful. Type A PON protection requires either manual intervention of the operator or a voltage-controlled optical switch to physically connect the spare fibre between the splitter and the OLT and to bypass the defect on the primary link. In addition, type A typically does not require an additional OLT PON port to be consumed for protection proposes as in the case of type B and type C.

5.2 Type B

In this configuration, protection is provided over the major areas of concern, which include feeder fibre and OLT equipment with separate OLT blades (or separate chassis in the case of dual-parented) for working and protection OLTs, as shown in Figure 3. No equipment redundancy is provided in the ONUs or feeder fibres. Thus, it does not provide ONU or full ODN protection. Type B provides the automated switching capability, but with an additional PON port on the OLT. The protection-capable OLT performs switching if the working PON fails without modification to the ONUs attached. Issues regarding monitoring of equipment and fibre on the protection link need to be addressed and as such are left up to the implementer of the OLT system.

If the OLT or feeder fibre is unavailable, all subscribers on that PON lose service. If an ONU or drop fibre is unavailable, only subscribers connected to that ONU lose service. Since the protection resources in type B are shared by all subscribers on that PON, the protection cost per subscriber is significantly lower than type C. Type B protection uses a $2 \times N$ optical power splitter which costs about the same as a $1 \times N$ splitter and introduces no additional optical loss. Link monitoring and switching may be automatic. As a result, this architecture is relatively simple, inexpensive and is of primary interest for most operators, especially for residential and small to medium-sized enterprises (SMEs).

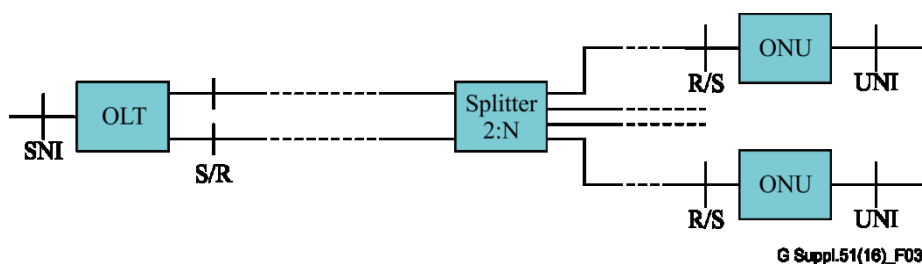


Figure 3 – Type B protection

5.3 Dual-parented type B protection

The standby OLT can reside together with the primary working OLT at the same central office location, but it is undesirable when protecting against catastrophic failures. To address this, one option is the use of dual-parented PONs as shown in Figure 4. In this example, any one subscriber is connected to two OLTs (working and protection) at different geographic locations via a $2 \times N$ optical splitter. During normal operation, the ONUs are ranged and communicate with the working OLT.

In the event of a fibre break, or an OLT equipment or node fault, the protection OLT can take over control of the PON. With dual parenting the OLTs can even be from different manufacturers. It should be noted that with dual parenting the process of duplicating the working OLT database to the protection OLT may need to be defined for interoperability reasons. If not, dual parenting may remain a proprietary method of PON protection.

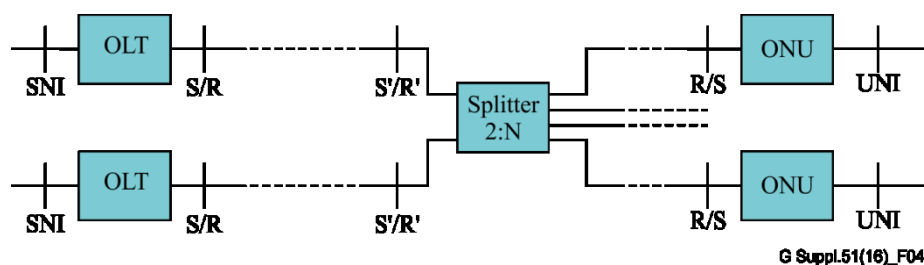


Figure 4 – Dual-parented type B protection

5.4 Type C protection

In this configuration, equipment redundancy is provided in the OLT, ODN and ONUs as shown in Figure 5. It provides two fully redundant links all the way into the subscriber's premises. It is the most costly, but provides the maximum availability. It is ideal for businesses and mobile back hauls. There are two options: linear 1 + 1 and linear 1:1 protection. In 1 + 1 protection, the protection PON is dedicated to each working PON. The normal traffic signal is copied and fed to both working and protection PONs with a permanent bridge between the two OLTs. Traffic of both is transmitted simultaneously to an ONU, which makes a selection between the two signals based on some predetermined criteria, such as server defect indication. In 1:1 protection, the normal traffic signal is transported either on the working PON or on the protection PON with automatic protection switching between OLTs.

The subscriber could have two separate ONUs, but this is not required. An ONU with two optical interfaces could be used.

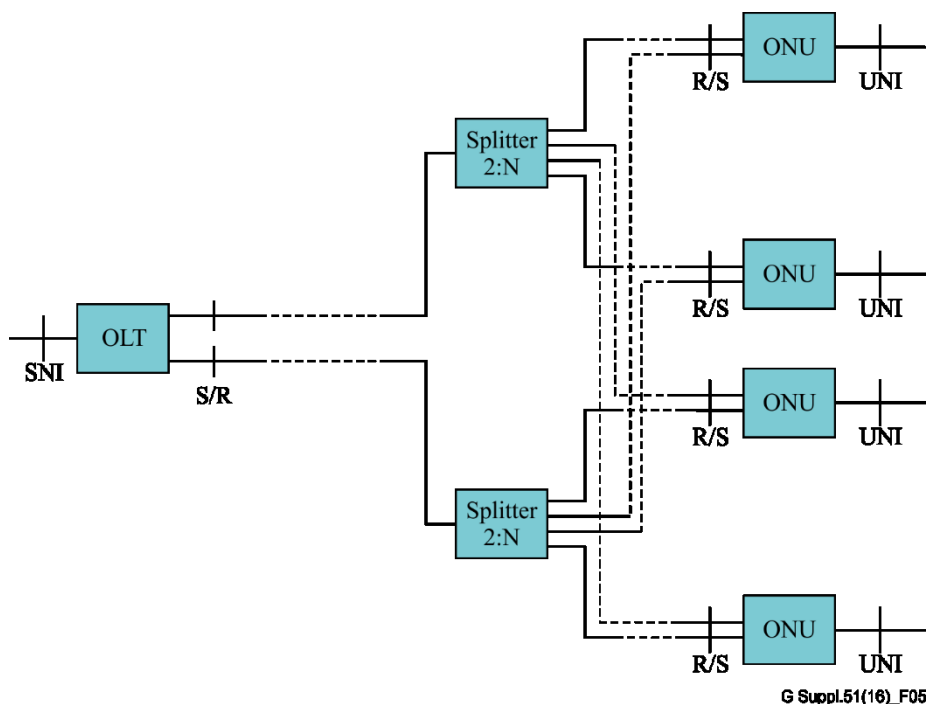


Figure 5 – Type C protection