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Passive optical network protection considerations

ITU-T G-series Recommendations – Supplement 51

ITU-T

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Supplement 51 to ITU-T G-series Recommendations

Passive optical network protection considerations

Summary

Passive optical networks 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 passive optical network (PON) redundancy and protection switching.

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

Supplement 51 to ITU-T G-series Recommendations 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

Edition	Recommendation	Approval	Study Group
1.0	ITU-T G suppl. 51	2012-05-11	15

FOREWORD

The International Telecommunication Union (ITU) is the United Nations specialized agency in the field of telecommunications, information and communication technologies (ICTs). The ITU Telecommunication Standardization Sector (ITU-T) is a permanent organ of ITU. ITU-T is responsible for studying technical, operating and tariff questions and issuing Recommendations on them with a view to standardizing telecommunications on a worldwide basis.

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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1 Scope

Passive optical networks are point-to-multipoint networks, much like wireless networks such as 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, which 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 that Recommendation, many other studies of different 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:

BA Bandwidth Allocation

BW Bandwidth

BNG Broadband Network Gateway

EMS Element Management System

EqD Equalization Delay

FIT Failures in Time

FTTH Fibre to the Home

FWI Forced Wakeup Indicator

HFC Hybrid Fibre Coax

ISDN Integrated Services Digital Network

LAG Link Aggregation

LOF Loss of Frame

LOS Loss of Signal

LSB Least Significant Bit

MAC Media Access Control

MTBF Mean Time Between Failures

MTTR Mean Time to Repair

NMS Network Management System

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
SLA	Service Level Agreement
SNI	Server Node Interface
TDM	Time Division Multiplex
UNI	User Network Interface
Wi-Fi	Wireless Fidelity

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 will 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 agreement (SLA) 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 QoS at least at the same level as that provided by the copper based plant. Presently, PONs are mostly poorly protected or not protected at all. Fibre cuts are not the only issue. Failure may occur in the OLT, ONU power splitter or optical amplifier, if employed.

3.1 PON system components – Failure rates

There have been several reports on the failure rates and time to repair for PON system components (see the bibliography). The 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. The table has references for the different sources used for the failure rates and times to repair for the different elements of the network.

3.2 FIT – Failures in time and MTBF

The failure of some network elements has more impact on services than others. For example, ONU failure or distribution fibre cut affects only one user. But a failure of OLT, feeder fibre or 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 FIT is the failure frequency in 10^9 hours and MTTR is the mean time to repair for 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 × MTTR × 10^{-9}

Another measure of failure rates is MTBF. It is the average time between failures for an MTBF or mean time between failures (hrs) = 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-Chen1]	2500	4	1×10^{-5}
	[b-Hajduczenia]	7000	5	3.5×10^{-5}
	[b-Chen2], [b-Tsubokawa]	NA	NA	NA
ONU	[b-Alcoa]	NA	NA	NA
	[b-Chen1]	256	24	6.1×10^{-6}
	[b-Hajduczenia]	2500	12	3×10^{-5}
	[b-Chen2], [b-Tsubokawa]	NA	NA	NA
Deployed optical fibre cable[a)]	[b-Alcoa]	10-250/km[b)]	NA	NA
	[b-Chen1]	NA	NA	NA
	[b-Hajduczenia]	200/km	14	2.8×10^{-6}
	[b-Chen2], [b-Tsubokawa]	18/km	6	6×10^{-11}
Splitter	[b-Alcoa]	NA	NA	NA
	[b-Chen1]	50-120	24	1.2×10^{-7} to 2.9×10^{-6}
	[b-Hajduczenia]	200	12	2.4×10^{-6}/km
	[b-Chen2], [b-Tsubokawa]	50-100	6	3×10^{-7} to 6×10^{-7}
Optical switch	[b-Alcoa]	NA	NA	NA
	[b-Chen1]	200	14	4.8×10^{-6}

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

Equipment	Reference	FIT	MTTR (h)	Unavailability
	[b-Hajduczenia]	NA	NA	NA
	[b-Chen2], [b-Tsubokawa]	NA	NA	NA
Some data shown are based on [b-Chen1], Table 5.1, and [b-Alcoa].				
a) NOTE – [b-GR-CORE-418] requires no more than 400 FIT per mile, equal to 250 FIT per kilometre. Also, the MTTR for [b-GR-CORE-418] is 6 hours not 24 hours.				
b) [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-CORE-418] has a requirement of less than 250 FIT/km).				

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-PON1 extended link budgets).

There are already several large-scale PON deployments around the world based on E-PON or G-PON. Efforts are under way to mature XG-PON or 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 may generally be residential services, 5 '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 5 '9s' or higher, based on service level agreements (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, flood, etc. 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 will also increase the probability that there may be a trunk fibre cut. In such networks, mean time to repair will also be longer.

In addition, PON reach extenders allow higher split ratios since the split ratios will not be limited due to the link budget used for long reach.

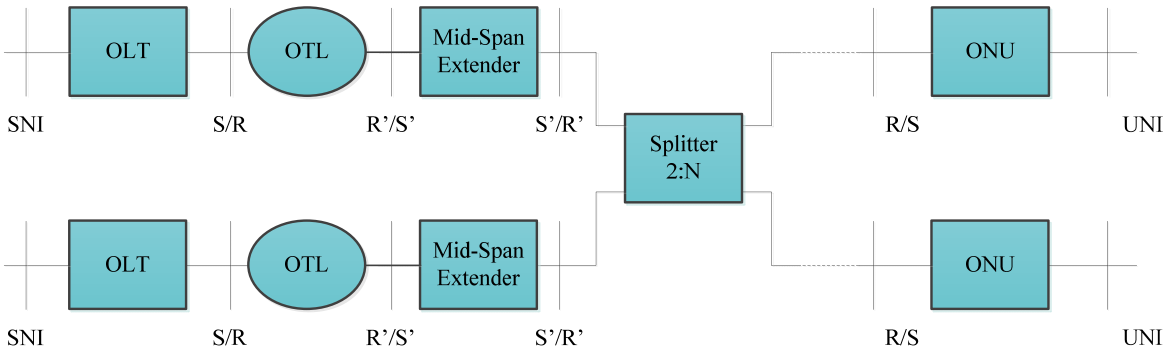

Figure 1 – Use case with reach extenders

4.4 Emergency services

Emergency services like hospitals, police, fire and 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 different 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 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. Thus, presently 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 it must 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 depend on cost and availability. A subscriber may have an SLA requirement of 5 '9s' (which means not more than 5.25 min failure in one 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 of 2011 in New Jersey, USA, hurricane Irene and untimely snow fall in October (when trees still had their leaves), caused serious damage to trees. Many trees fell over power and communication cables hanging on poles causing disruption of electric power and communication for several days in several thousand homes and businesses.

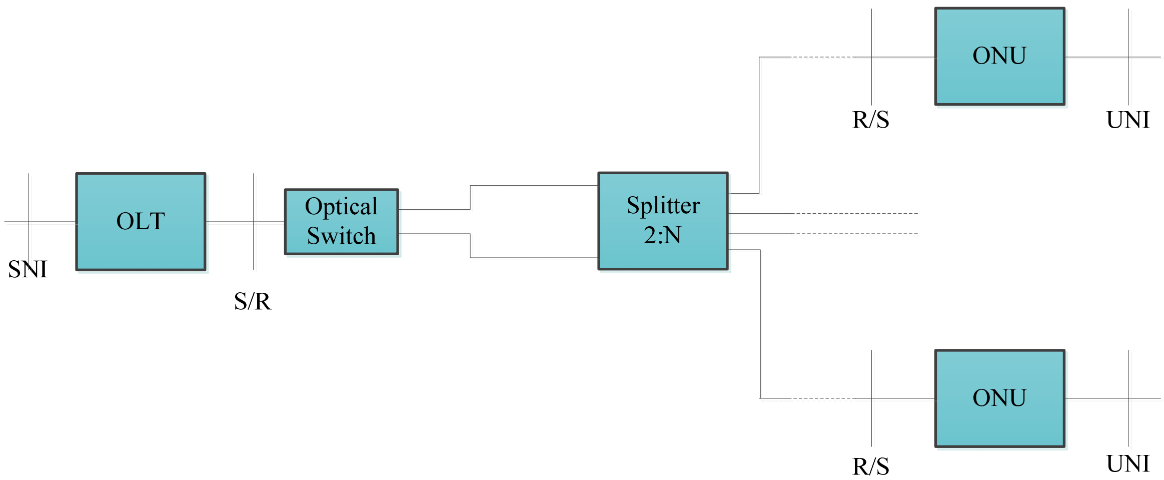

Figure 2 – Type A PON protection

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 PON lose service. If an ONU or drop fibre is unavailable, only subscriber(s) 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 × N optical power splitter which costs about the same as a 1x N splitter and introduces no additional optical loss. Link monitoring and switching may be automatic. As a result, this architecture is relatively simple, cheap and is of primary interest for most operators, especially for residential and small/medium-sized businesses.

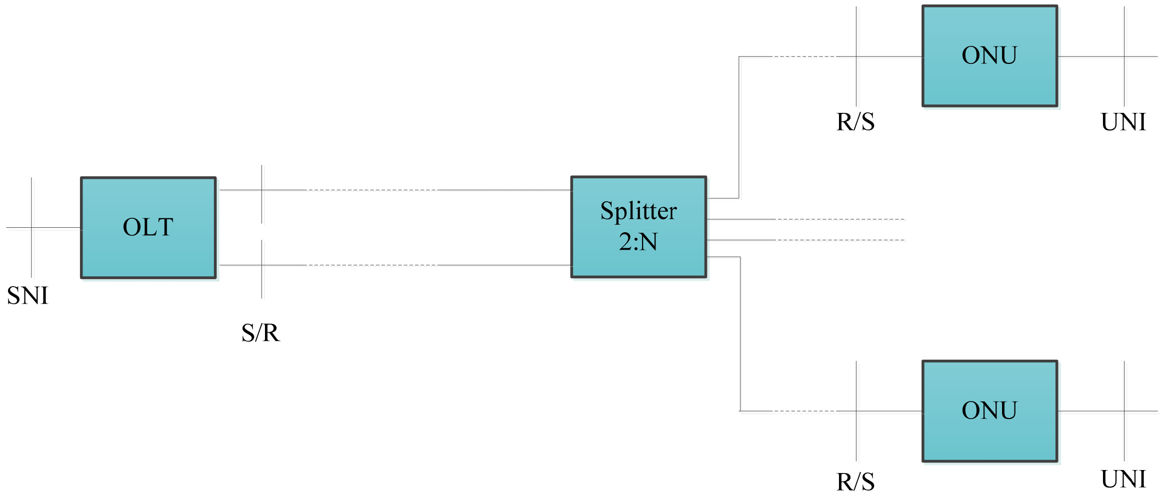

Figure 3 – Type B protection

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 2x N optical splitter. During normal operation, the ONUs are ranged, and communicate with the working OLT. In the event of a fibre break or the 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.

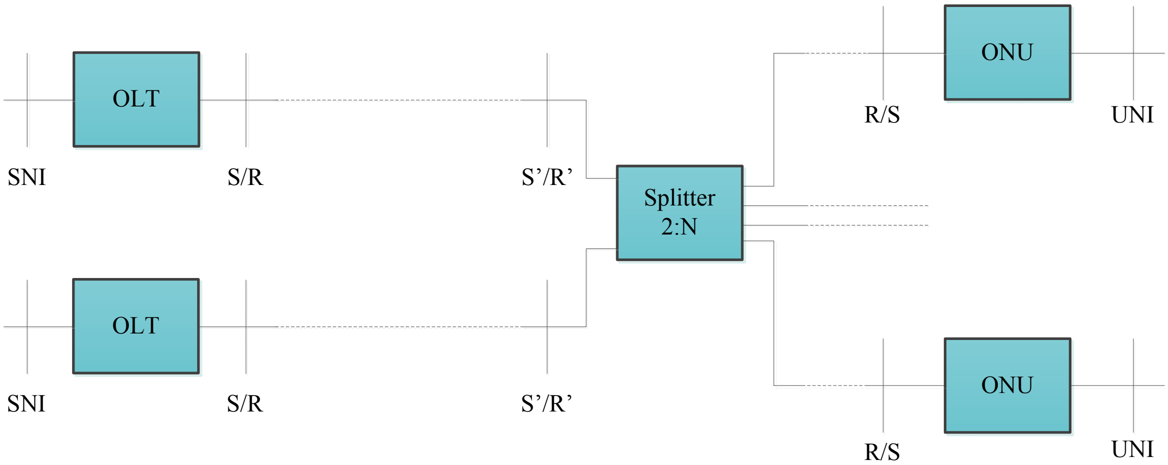

Figure 4 – Dual parented Type B protection

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 protections. 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.

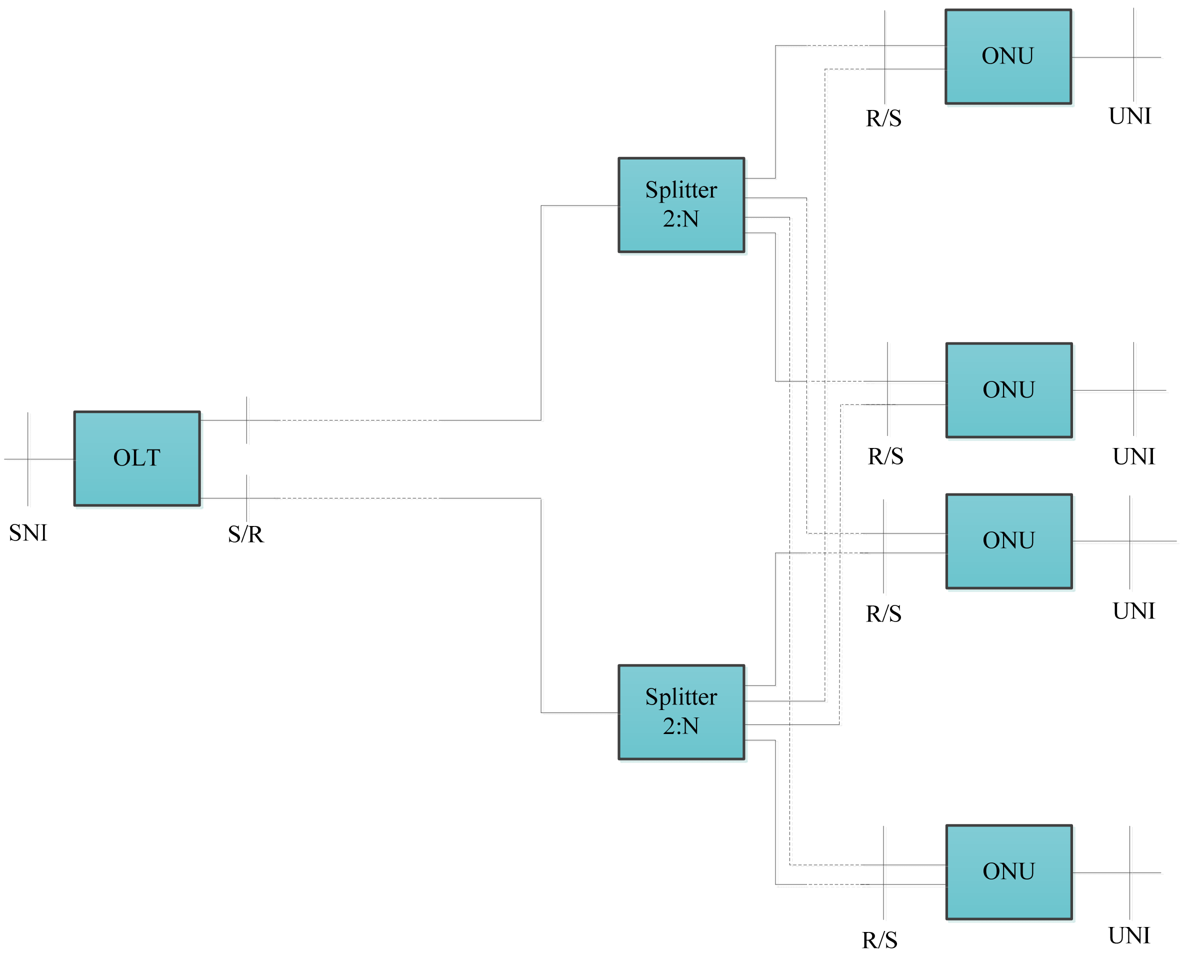

Figure 5 – Type C protection

5.5 Extra traffic for Type C protection

Type C protection is ideal for delivering extra traffic which can be carried over the protection path while the primary working PON is active. This option provides effective usage of bandwidth in the protection resources. The extra traffic will not be protected. The operator must have an option not to activate this extra traffic.

5.6 Type C protection using link aggregation

Strictly speaking, this should not be considered "PON protection" as it makes no demands upon the PON equipment to switch. Topologically this approach looks identical to Figure 5, however, unlike true Type C protection, the ONU does not have redundant optical transceivers but rather the ONUs are duplicated, one ONU to each PON. Similarly, the OLTs are completely duplicated as was done with dual homing. All of the service protection is done with the use of link aggregation (LAG) and the UNI and SNI interfaces from the ONU and OLT, respectively. In this approach the PONs may be considered simple Ethernet links. Similar to the 'extra traffic' approach, under normal operation the aggregate traffic can be double that of a single PON, via this use of LAG. As in the previous clause, the extra traffic will again not be protected.

5.7 Type D – Deprecated

Type D protection, while originally in [b-ITU-T G.984.1], has since been deprecated.

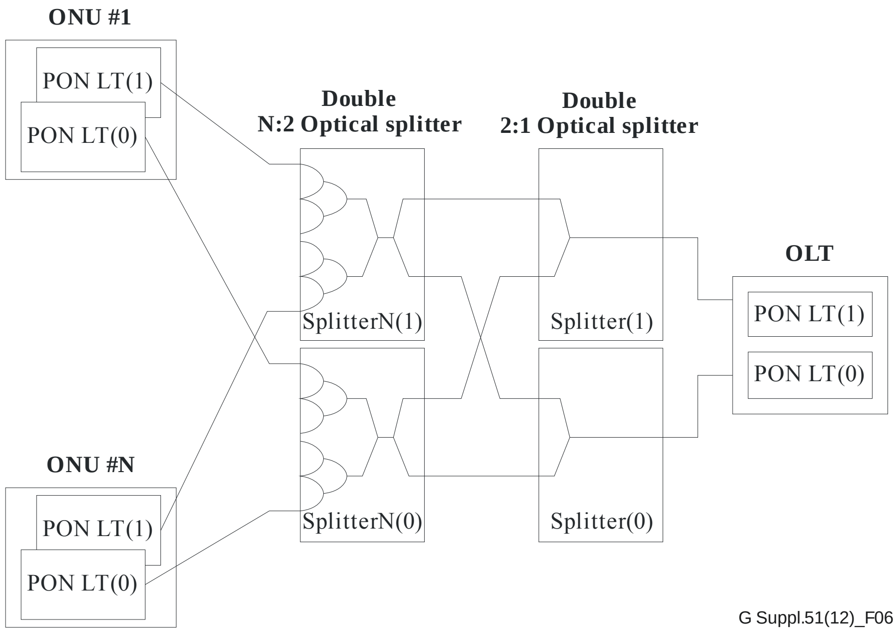

Figure 6 – Type D – Deprecated

5.8 Type B with N:1

In this architecture, one OLT protects multiple, say N, number of PONs through an optical switch as shown in Figure 7, or as shall be seen by manual pre-configuration for the use case of PON maintenance. The N × 1 optical switch could be a simple mechanical motorized device which can connect the backup OLT to any working PON. It reduces the total cost but there is an added cost of an optical switch, which is also an active element. Furthermore, if several working fibres share the same ODN duct and there is damage to more than one working fibre, this protection is insufficient. In the use case of PON maintenance, a virtual N:1 Type B can be done by manual pre-configuration. In this case, a spare OLT line card is initially in the OLT chassis or prior to system upgrade a spare card is installed. The spare feeder fibre(s) of the PON(s) to be upgraded is connected to the spare OLT port(s). Prior to switching, the spare OLT must obtain the database of the working OLT to maintain normal operation after a switch. Once the spare OLT is ready to act as a backup, the operator initiates a forced PON protection switch. As stated before, for this method to be useful, the switching must occur much faster than the length of time a PON might recover if no fast recovery method (as detailed in clauses below) is used. Switching times in the milliseconds are desirable.

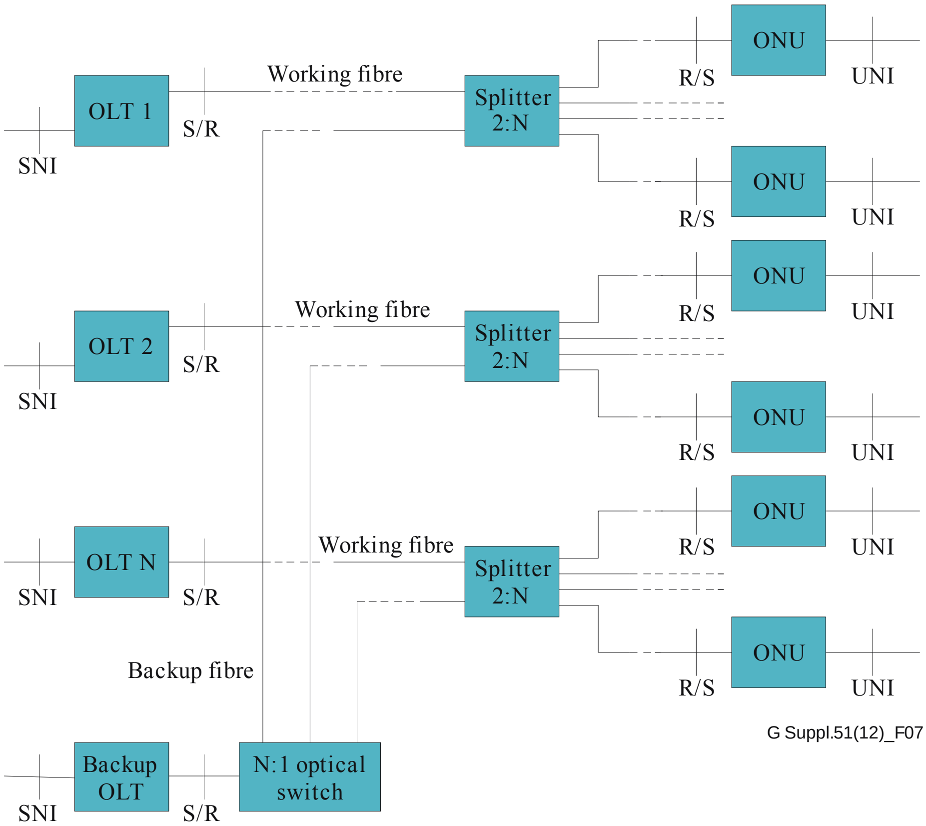

Figure 7 – Type B with N:1 using optical switch

6 Availability and switching speed goals

There is often a correlation between availability requirements and PON switching speed goals. This is not always the case, however. In the case of planned PON maintenance, it may be possible to achieve availability requirements without fast switching speeds. However, it is highly undesirable to induce the loss of service for minutes (or even seconds) on a planned basis. The allowed unavailability times are generally intended to be reserved for outages of an unplanned nature.

6.1 Availability in an unprotected PON

An unprotected PON system consists of an OLT, a feeder fibre, an optical splitter, dropping fibres and ONUs (in the case of concentrated splitting). Unavailable probability attributed to each component, U_i, and the system availability, A, are expressed as:

$$U_i = \frac{MTTR_i}{MTBF_i + MTTR_i}$$

and

$$A = 1 - \sum_{i}^{N} U_i$$

respectively, where i indicates an identifier of each component. Examples of MTBF and MTTR of each component are shown in Table 1.

The values in Table 1 are just examples, as MTBF depends on the component design, manufacturing process and practice. The MTBF of the OLT depends on its implementation and configuration such as the type of SNI and the number of PON ports per card. The MTBF of the ONU depends on its implementation and configuration such as the type of UNI and the number of UNI ports.

The fibre and splitter are passive components, so the MTBF is very large compared to the OLT/ONU as a device. However, human/animal/natural-induced breaks can occur in these devices depending on the deployment and operational situation of the PON. The deployment and operational situation is very different operator by operator and/or area by area: probability of fibre cuts is very different between underground and aerial, for example, and the situation of the underground space is also very different case by case.

MTTR also depends on the operational situation. But, it is likely that it can be several hours for equipment in the central office to replace the failed card from inventory, while it can be 8 to 24 hours or more to replace outside plant and customer equipment, considering field work needed and delivery time.

In conclusion, the system availability is limited by the OLT/ONU in some cases, and limited by fibre and splitter in addition in some other cases.

In addition, it is important to consider not only the availability but also the outage scale in telecommunication operators. For example, the outage scale of OLT failure (or feeder-fibre break) is large, e.g., 32 to 64 while that of ONU failure is only 1. Therefore, the OLT failure is considered more important in terms of inducing a simultaneous outage. While not directly related to availability, the impact of a large-scale outage can have other consequences such as customer loss and public relations problems.

6.2 Assumptions for availability calculations

Using the values in Table 1 and the formula for availability, the availability of PON without protection can be determined.

To calculate availability assumptions must be made about the FIT/MTBF and MTTR of the various network components. Table 2 lists the assumptions to be used in the following examples, which are based loosely on the FIT and MTTR numbers of Table 1. Other numbers may be used, although it shall be seen that availability is often dominated by one or two components.

Table 2 – Assumptions for availability calculations

Component	Assumption
Feeder fibre length	18 km
Feeder fibre FIT	18 km × 200/km = 3600
Drop fibre length	2 km
Drop fibre FIT	2 km × 200/km = 400
Fibre MTTR	24 hours
OLT FIT	2500
OLT MTTR	4 hours
ONU FIT	256
ONU MTTR	24 hours
Splitter FIT	100

Note that the fibre FIT chosen is a value between the aerial 10 FIT and the buried 250 FIT, simply as an example.

6.3 Availability of an unprotected PON

The relationship between the MTBF and FIT is as follows:

$$\text{MTBF}_{\text{OLT}} = \frac{1\,000\,000\,000}{\text{FIT}_{\text{ OLT}}}$$

Therefore:

OLT MTBF: 400 000 hours

Using the same formula:

ONU MTBF: 3 900 000 hours

Feeder fibre MTBF: 278 000 hours

Drop fibre MTBF: 2 500 000 hours

Based on the availability formula, the overall access network availability will be:

$$\text{A} = 1 - \left(\frac{\text{MTTR}_{\text{OLT}}}{\text{MTBF}_{\text{OLT}}+\text{MTTR}_{\text{OLT}}} + \frac{\text{MTTR}_{\text{ONU}}}{\text{MTBF}_{\text{ONU}}+\text{MTTR}_{\text{ONU}}} + \frac{\text{MTTR}_{\text{FF}}}{\text{MTBF}_{\text{FF}}+\text{MTTR}_{\text{FF}}} + \frac{\text{MTTR}_{\text{DF}}}{\text{MTBF}_{\text{DF}}+\text{MTTR}_{\text{DF}}}\right)$$

The MTTR in the denominators is negligible compared to the MTBF, therefore, for an unprotected PON:

$$\text{A} = 1 - \left(\frac{4}{400\,000} + \frac{24}{3\,900\,000} + \frac{24}{278\,000} + \frac{24}{2\,500\,000}\right) = 99.988\%$$

This is only one example; the fibre reliability in many cases is better than that used here and availability would improve accordingly. However, achieving 5 '9s' is very unlikely in an unprotected configuration.

6.4 Protection path monitoring

It is an equally likely occurrence that backup components have failed when switching from active systems to backup systems, if not monitored. High levels of availability cannot be achieved without protection path monitoring. In the case of 1:1 protection a method must be used to determine that the protection fibre is intact, as well as the protection OLT optics and electronics. The OLT receive path can be used to monitor upstream transmissions to ensure the protection fibre is functioning. With Type B protection, the OLT transmitter cannot be used without impacting the functioning of the PON. If the OLT is not exercising the transmitter it is unlikely to fail, however. One approach is to test the protection system periodically in a maintenance window. In this case, protection speed is of critical importance for high availability services.

In another example, in Type B with N:1, it is important to check the condition of the optical switch and backup OLT in the normal state. One monitoring method is to compare the received upstream frame between the active OLT and the backup OLT. If they differ from each other in terms of the number of received frame count or upstream bit error rate, the backup OLT may be intentionally failed.

Thus, by periodically monitoring the protection path, the protected section can maintain a standby state without failure.

6.5 Switching speed and impact on availability

The impact of switching speed on availability depends on the protection architecture used, as well as the FIT and MTTR for the various components. Examples are shown below that provide some insight into switching speed requirements. Note that while overall service availability will depend on additional network factors beyond the access network, these examples will be limited only to the access network. An additional margin must be built into the system to achieve overall service availability.

6.5.1 Calculating availability for Type B and Type C scenarios

Note that for the examples below the probability that a backup component will fail at the same time as the primary component will be considered negligible. This failure probability can be included into the formula below by squaring the unavailability of any component that is protected.

Example 1: Type B protection availability – 60-second recovery speed

Using the same assumptions as with the unprotected PON but changing the MTTR from 4 hours for the OLT and 24 hours for the feeder fibre to 60 seconds (0.017 hours) gives:

$$A = 1 - \left(\frac{0.017}{400\,000} + \frac{24}{3\,900\,000} + \frac{0.017}{278\,000} + \frac{24}{2\,500\,000}\right) = 99.998414\%$$

Example 2: Type B protection availability – 50-millisecond recovery speed

Using the same assumptions as above but changing the Type B switching speed from 1 minute to 50 milliseconds gives:

$$A = 1 - \left(\frac{1.4\text{x}10^{-8}}{400\,000} + \frac{24}{3\,900\,000} + \frac{1.4\text{x}10^{-8}}{278\,000} + \frac{24}{2\,500\,000}\right) = 99.998424\%$$

As can be seen, there is almost no impact on availability by protection switching detection and recovery speed in a Type B scheme. Even a 5-minute recovery time would not significantly impact the availability, in this case. Note that higher availability of the drop fibre and feeder fibre would increase the overall availability, and longer recovery times would then become a limiting factor.

It should be noted that Type B can 'almost' meet five '9s' of availability. The dominant sources of unavailability are on the unprotected parts of the network, the drop fibre and the ONU. If the MTTR of these were improved five '9s' could be met, but barely. Given other sources of availability outside of the access network, to reliably achieve five '9s' one should look to the Type C architecture.

It must be emphasized that the above discussion does not preclude the need for switching speeds of much less than 60 seconds because (1) the FIT/MTTR in the above calculations are just examples and switching can be much faster depending on the manufacturing scheme of the OLT/ONU as well as operational situation of fibres/splitters as described in clause 6.1, and (2) a shorter switching speed leads to shortening the time of simultaneous service failures for subscribers under the same OLT, which can be up to 256 (as per [b-ITU-T G.987.1]) in the Type B protection. In the case where the network operator wants to avoid any simultaneous breaks of T1/E1 or POTS/ISDN connections (typically provided via emulation) under the same OLT, it is valid to implement a 50- to 120-millisecond switching time as described in clause 14.3 of [b-ITU-T G.984.1]. Also, 1 second should be a good target as a simultaneous outage of a broadcast service via FTTH. As has been discussed above, the use case of planned PON upgrades requires sub-second and even 50- to 120-millisecond switching times.

Example 3: Type C protection availability – 60-second recovery speed

With Type C protection, very high levels of availability can be expected. In this case, the recovery times will become a more significant factor. Again, start the process with the formula below:

$$A = 1 - \left(\frac{MTTR_{OLT}}{MTBF_{OLT}+MTTR_{OLT}} + \frac{MTTR_{ONU}}{MTBF_{ONU}+MTTR_{ONU}} + \frac{MTTR_{FF}}{MTBF_{FF}+MTTR_{FF}} + \frac{MTTR_{DF}}{MTBF_{DF}+MTTR_{DF}}\right)$$

The difference now will be that the MTTR of all of the components will be relatively fast.

$$A = 1 - \left(\frac{0.083}{400\,000} + \frac{0.083}{3\,900\,000} + \frac{0.083}{278\,000} + \frac{0.083}{2\,500\,000}\right) = 99.99975\%$$

Example 4: Type C protection availability – 5-second recovery speed

Likewise for a 5-second recovery:

$$A = 1 - \left(\frac{0.017}{400\,000} + \frac{0.017}{3\,900\,000} + \frac{0.017}{278\,000} + \frac{0.017}{2\,500\,000}\right) = 99.99998\%$$

Example 5: Type C protection availability – 50-millisecond recovery speed

And for a 50-millisecond recovery:

$$A = 1 - \left(\frac{1.4\text{x}10^{-8}}{400\,000} + \frac{1.4\text{x}10^{-8}}{3\,900\,000} + \frac{1.4\text{x}10^{-8}}{278\,000} + \frac{1.4\text{x}10^{-8}}{2\,500\,000}\right) = 99.99999999999\%$$

Even if Type C protection allows for five '9s' of availability with a slow switching speed of 1 minute, it is again emphasized that the above discussion does not preclude the use of switching speeds of less than 60 seconds, as explained above.

7 Fast failure detection

In the case of a break in the fibre ODN, there will be multiple ONUs that enter the POPUP state in GPON or LODS state in the XG-PON1. Accordingly, a LOS alarm will be reported for the whole PON interface in the working OLT as a complete PON failure, to indicate that the working OLT did not receive any expected transmissions in the upstream.

If protection switching has been implemented, the OLT may switch all ONUs upon failure to the protection fibres with schemes illustrated in clause 5. There is a relationship between the detection time, the frequency of the allocations and how well the OLT can recover the upstream bursts. A fibre cut or fibre pull is not an instantaneous event and can present itself as a reduction in the received power level at the OLT, as shown in Figure 8. Therefore, depending on the location of the ONU relative to the OLT and the nature of the fibre cut, the detection time may vary. An ONU that is relatively far away from the OLT may be impacted by a fibre cut faster than one that is closer.

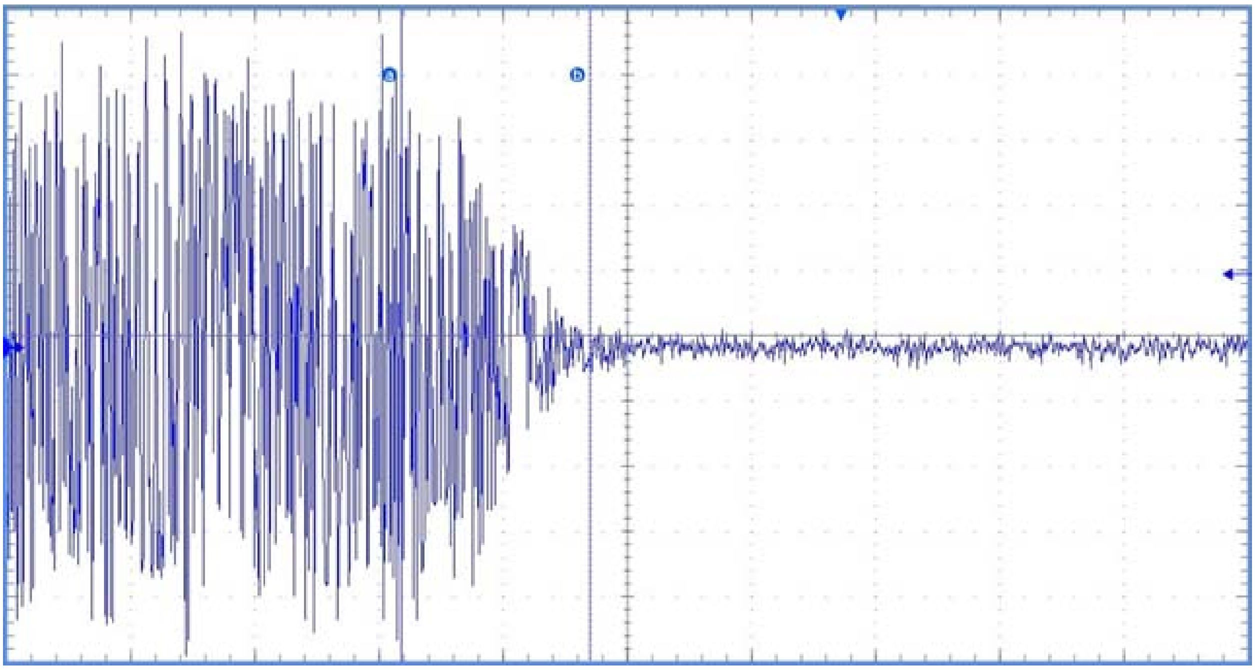

Figure 8 – Example trace of gradual loss of signal upon fibre cut

Other alarms generated by the OLT may be treated as a condition for fast failure detection. For example, when SDi or SFi alarms appear in the OLT for all activated ONUs as an indication of link quality degradation, protection switchover may be triggered to enable the ONU to work in the backup path, while field engineers can detect possible issues in the fibre of the working path without affecting services.

Service providers may select other conditions to monitor the system performance and enable protection switchover accordingly, however, this is beyond the scope of this Supplement.

Note the duality of the requirements. If the fast failure detection and switchover is the priority, then it is reasonable to assume that the backup OLT remains powered up during the primary OLT operation, thus introducing an additional power consuming element of the access system. If ONU power saving is the priority, so that ONUs may be intermittently placed in the lower power mode with limited communication capabilities, then it is natural to expect the failure detection and service restoration time upon switchover event to be negatively affected.

To take control over the ONUs in a protection-switching event, the backup OLT must obtain the necessary configuration and status information on the subtending ONUs.

There are three ways for the backup OLT to collect the ONU's configuration and status information.

– The primary and backup OLT each communicate with the management system and the management system relays the necessary primary information to the backup OLT. This is a slow channel that is more suited for conveying the configuration information rather than dynamic status.

– The backup OLT may snoop the upstream transmissions while remaining passive in the downstream. This channel requires the backup OLT to be permanently powered up and is functionally limited in a sense of unidirectionality and the lack of acknowledgment.

– The primary and backup OLT may communicate via a direct channel similar to that conventionally employed in systems with high service availability requirements. Such a channel is not currently specified in the PON system context.

In an XG-PON system with deployed ONU power management functionality, the backup OLT can snoop the power-saving mode status of the ONUs by observing the upstream sleep-request PLOAM messages. Upon the protection switching event, the backup OLT can be expected to forcibly wake up the ONUs by setting the forced wakeup indicator (FWI) bit in BW allocation or sending PLOAM messages indicating SA(OFF) in the downstream. Then, those ONUs may activate the power-saving mechanism later by negotiating with the backup OLT again.

8 Fast protection switchover mechanisms

Type B protection is the most popular protection architecture described in clause 14.2.1 of [b-ITU-T G.984.1], as shown in Figure 3, which has been deployed widely in the world. ONUs under a protection scheme are protected by an OLT group which is composed of two OLTs, where one OLT is in the operational state (referred to as the working primary OLT) and the other one is a backup unit (referred to as the backup OLT). The data path connected to the working primary OLT is referred to as the primary (main) path, and the data path connected to the backup OLT is referred to as the backup path.

If reach extenders (REs) are deployed in the signal paths between the OLT and the ONUs, then the Type B protection architecture could be extended as shown in Figure 9 ([b-ITU-T G.984.6], Figure III.1). Due to extended link length, the risk of damage to the fibre increases, and, therefore, [b-ITU-T G.984.6] stipulates the need for OTL protection.

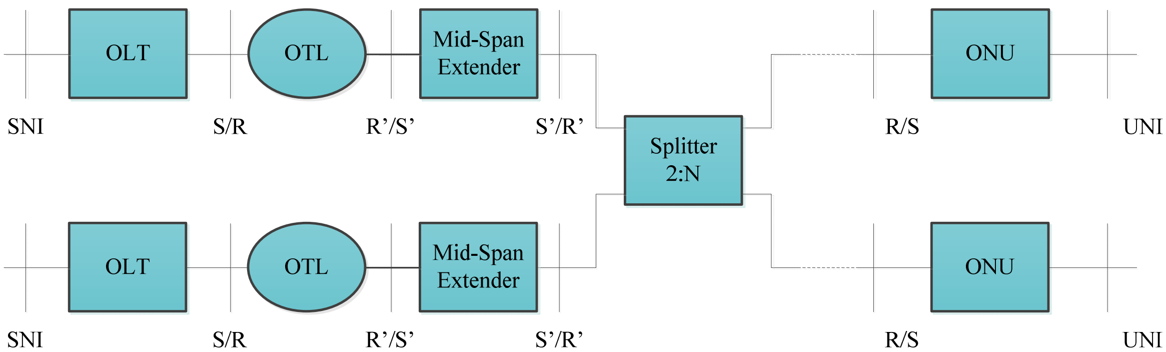

Figure 9 – Extended Type B protection architecture with two independent RE units

Since the same wavelength is used in the downstream channel in both the primary and backup paths, the backup OLT cannot range any of the ONUs connected to the primary OLT via the regular ranging mechanism. In order to achieve a fast switchover, it is desirable to shorten the re-ranging processing as much as possible. There are four ways to meet this objective:

1) ranging before switchover (pre-ranging);
2) ranging after switchover (limited re-ranging);
3) no pre-configuration of standby OLT EqD values per ONU (fast ranging);
4) equalization-delay-agnostic.

Under approach 1), all ONUs are provided with the EqDs for the primary and backup paths, effectively minimizing the time it takes to transition between operating states for the primary and backup paths. When the line failure is detected and the path switchover takes place, the ONUs are already prepared for operation on the backup path.

Under approach 2), the need to save time leads to a requirement to limit the ranging process taking place after switchover. Such limited re-ranging can be achieved if just a small subset of ONUs is ranged, while the EqDs for the others are derived through indirect means.

Under approach 3), all ONUs will be able to be sequentially ranged by the re-scheduled upstream arrangement, to accomplish the restoration.

Under approach 4), the ONUs retain the primary equalization delays after the protection-switching event, with drift being mitigated by the backup OLT (see clause 8.4).

8.1 Ranging before switchover (pre-ranging)

This mechanism allows for the backup OLT to measure the RTD for the backup path without affecting the working OLT.

Mechanisms for ranging before switchover (pre-ranging):

The working OLT sends out a Ranging_Request bandwidth allocation (BA) to a target ONU, and the target ONU responds with the Serial_Number_ONU PLOAMu message, which is received by both the working OLT and backup OLT. Based on the transmission time of Ranging_Request BA and the reception times of the Serial_Number_ONU PLOAMu message in the two OLTs, the RTD between the backup OLT and target ONU can be measured and calculated.

The relationship between individual time parameters and references used during the ranging procedure is shown in Figures 10 and 11.

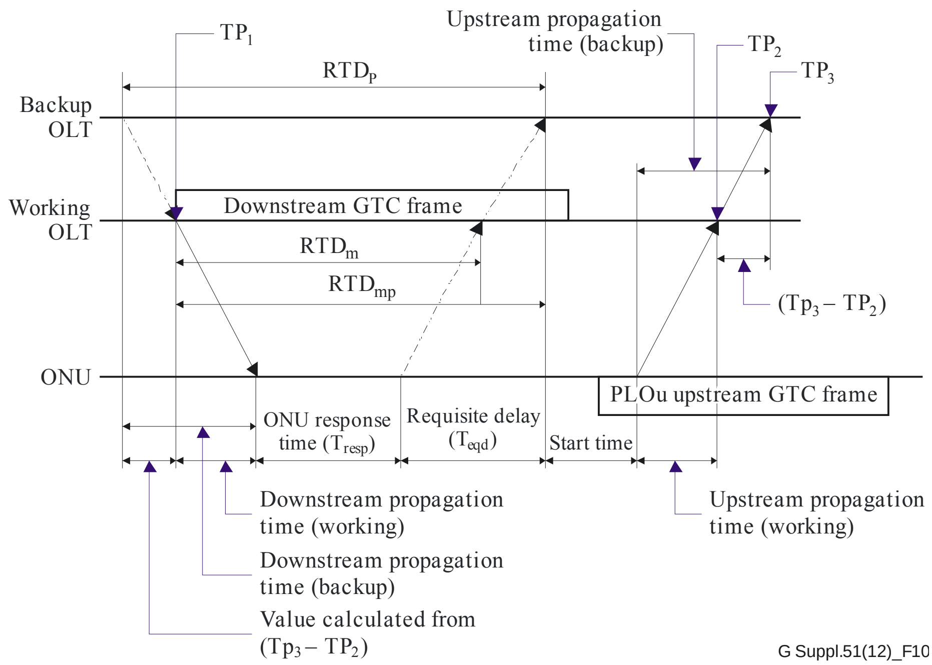

Figure 10 – Relationship between time references when the backup path is longer than the working path

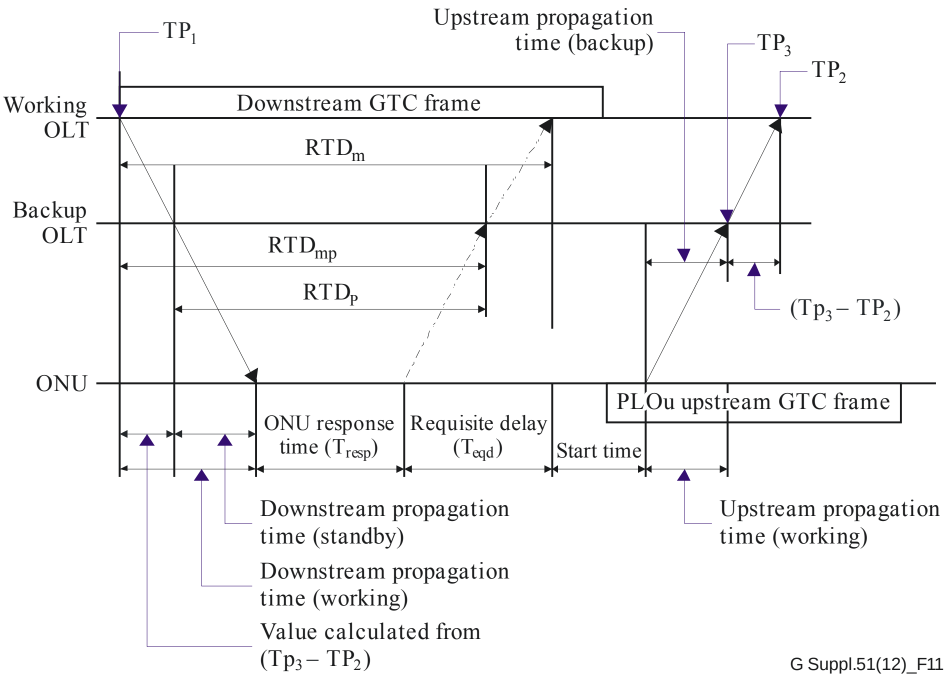

Figure 11 – Relationship between time references when the backup path is shorter than the working path

This mechanism comprises the following steps.

1. The working OLT sends a Ranging_Request BA (as specified in clause 10.2.5.2 of [b-ITU-T G.984.3]) to the given ONU, and records the time (TP_1) when the Ranging_Request BA is transmitted.
2. The target ONU responds with a Serial_Number_ONU PLOAMu message at the StartTime assigned in Ranging_Request BA, after a fixed ONU response time (T_{resp}), and requisite delay (T_{rd}). The PLOAMu message can be received by both the working and backup OLTs.
3. The working OLT records the time (TP_2) when the Serial_Number_ONU PLOAMu message is received by the working OLT.
4. The working OLT calculates RTD_m and EqD_m for the working path.
5. The backup OLT records the time (TP_3) when the Serial_Number_ONU PLOAMu message is received by the backup OLT.
6. The RTD_p and EqD_p for the backup path can be calculated based on Equations (1) – (2), where the RTD_{mp} denotes the round trip propagation delay for signal transmission from the working OLT to the target ONU and back from the target ONU to the backup OLT.

$$RTD_p = RTD_{mp} + (TP_3 - TP_2) = RTD_m + 2 \times (TP_3 - TP_2) \quad (1)$$

$$EqD_p = EqD_m - (RTD_p - RTD_m) = EqD_m - 2 \times (TP_3 - TP_2) \quad (2)$$

EqD_p can be sent by the working OLT to the target ONU via Ranging_Time PLOAMd message (LSB of byte 3 in the Ranging_Time PLOAMd message can be used to indicate whether the EqD_p is applied to the working or backup path, see clause 9.2.3.4 of [b-ITU-T G.984.3]) and used immediately after switching is completed without re-ranging.

8.2 Ranging after switchover (limited re-ranging)

For the case of limited re-ranging, the fewer ONUs that require re-ranging, the more switchover time is saved. The key is to keep the number of re-ranged ONUs as small as possible. Fortunately, Type B protection has its own features of facilitating the minimum number: only the feeder fibre section is protected. As a result in timing relationships, the only difference between the working path and backup path is the possibly different RTDs caused by the possibly different lengths of the two trunk fibres. Therefore, it can easily be observed that the differences of the pre-switchover transmission time and the post-switchover transmission time are the same for all ONUs in the same system. It makes senses that the OLT obtains this "common transmission time difference" by just re-ranging any one of the connected ONUs, instead of completing a ranging process for every ONU. Then all the other EqDs could be updated by a simple calculation based on this information.

So in the case of Type B, the best way of doing a limited re-ranging is to range only one ONU after switchover. The following clauses describe the recommended procedure.

8.2.1 Assumptions

Doing a limited ranging implies that all working path EqDs must be known by the backup OLT. Several basic ways are suggested of implementing this.

1. The pre-switchover EqDs are timely updated between the working OLT and the backup OLT once they are updated at the working section.
2. The pre-switchover EqDs are periodically updated between the working OLT and the backup OLT.
3. The pre-switchover EqDs are issued from the working OLT to the backup OLT during the switchover action.

Though it is determined by the OLT's specific implementations, it is recommended that the EqD updating procedure be completed as quickly as possible.

8.2.2 Notations

RTD – Time interval at the OLT between transmission of a downstream frame and reception of a corresponding upstream burst from the given ONU. This time is composed of the round-trip propagation delay, and the ONU response time. See clause 10.1.1 of [b-ITU-T G.984.3].

Δ_{Rtd} – The time difference between the $RTD_{working}$ and RTD_{backup}. In the case of common feeder fibre, $\Delta_{Rtd,n} = \Delta_{Rtd,chosen\ ONU}$. Here, the chosen ONU refers to the ONU which is chosen from the working ONUs online.

Teqd – The "zero distance" equalization delay, equal to the offset between the downstream and upstream frames at the OLT location. The OLT adjusts the equalization delay of each ONU such that, for all ONUs, the start of the upstream frame at the OLT occurs Teqd seconds after the start of the downstream frame. See clause 10.4.3.3 of [b-ITU-T G.984.3].

EqD – The requisite delay assigned by the OLT to an individual ONU as a result of ranging. By adjusting their local transmission times with this value, all the ONUs are viewed as at the same distance from the OLT. See clause 10.1.1 of [b-ITU-T G.984.3].

8.2.3 Fast switchover procedure

The following process is provided for a Type B protection fast switching while fatal corruption happens to the working section.

1. All ONUs detect LOS/LOF alarm and transit from the Operation state (O5) to POPUP state (O6).
2. The backup OLT is activated while the original working OLT becomes silent.
3. The backup OLT issues a broadcast POPUP message.
4. On receiving this broadcast message, all the connected ONUs transit from O6 to O4 (ranging state).
5. One of the ONUs is randomly chosen to be re-ranged.

$$EqD_{backup,n} = T_{EqD,n} - \left\{RTD_{working,n} - \left\lfloor Rtd_{(working,chosenONT)} - Rtd_{(backup,chosenONT)} \right\rfloor\right\}$$

6. The backup OLT sends a ranging time PLOAM message with the updated EqD to every ONU.
7. On receiving this message, all the ONUs go to the Operation state (O5).

The whole system works normally again.

8.3 No pre-configuration of standby OLT EqD values per ONU (fast ranging)

1) OLT configured to use all resources to recover ONUs upon failure detection:

   Upon the detection of a loss of PON or OLT failure, the backup OLT will change the upstream map to schedule all upstream resources to allow ONUs to sequentially range, as opposed to data grants.

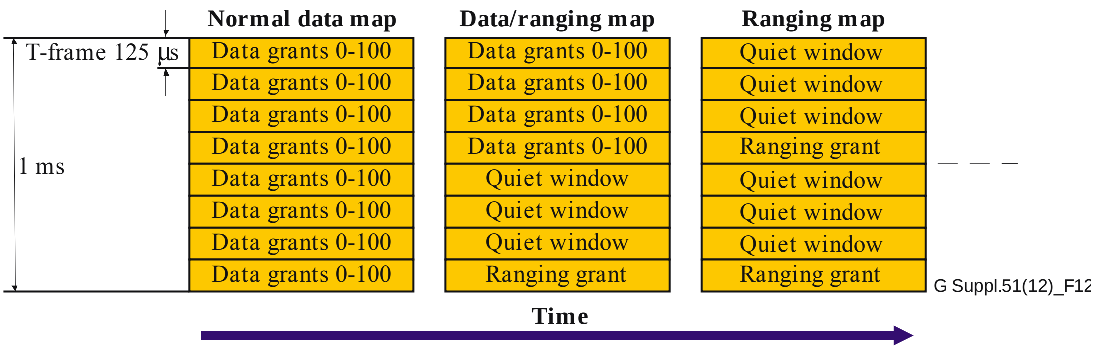

Figure 12 – Schedule of all upstream resources to allow ONUs to sequentially range

ONUs are configured to go to the O6 state upon LOS and return directly to the O5 state upon recovery of the downstream sync in the XG-PON1 system, or to the O4 state upon receiving a broadcast POPUP message in the GPON system.

8.4 Equalization-delay-agnostic protection switch

In a practical network, if the ONUs retain the primary equalization delays after a protection-switching event, the adjusted round-trip times observed by the backup OLT are no longer identical. ONUs are transmitting on generally different wavelengths with different refractive indices, and the response times may change due to the serializer/deserializer phase randomization. The aggregate relative drift caused by these effects, however, can be bounded and will not exceed a few tens of bit times. The backup OLT can mitigate the drift by providing additional guard time between the upstream bursts in the bandwidth maps. Furthermore, depending on the mechanisms offered by the TC layer of a particular PON system, the backup OLT may re-acquire the ranging information without the service interruptions associated with the opening of quiet windows.

Prior to switchover, the backup OLT obtains the ODN design parameters and the value of the primary upstream PHY offset, Tmax, via an offline management channel.

Upon the switchover, the backup OLT proceeds as follows.

1) The backup OLT ensures that the subtending ONUs are in the Operation state O5. In XG-PON, this is achieved by virtue of a well-formed downstream transmission. In G-PON, an individual directed POPUP message may be required, unless a new broadcast Swift_POPUP message (see [b-ITU-T G.984.3] Amendment 3) can be used to bring the ONUs in the POPUP state directly into the O5 state.
2) The backup OLT schedules the upstream transmissions by forming a bandwidth map with extended guard times between the individual bursts and relating them to a yet unknown upstream PHY frame reference.

3) The backup OLT detects the individual upstream transmissions and observes the adjusted round-trip times of the subtending ONUs. The adjusted round-trip times form a distribution with bounded support.

4) The backup OLT selects an interim upstream PHY frame offset to be not less than the largest observed round-trip time.

5) The backup OLT issues individual relative equalization delay adjustments to align the ONUs at the selected interim upstream PHY frame offset. This is done with an available Ranging_Time message in XG-PON and with a new Ranging_Adjustment message in G-PON (see [b-ITU-T G.984.3] Amendment 3).

6) The backup OLT may adjust the upstream PHY frame offset at the desired value by issuing a broadcast relative equalization delay adjustment. This is done with an available Ranging_Time message in XG-PON or with a new Ranging_Adjustment message in G-PON (see [b-ITU-T G.984.3] Amendment 3).

7) The backup OLT restores the normal guard times in the bandwidth maps.

In the subsequent operation, the backup OLT, which has become the serving OLT, conducts service as usual, including discovery and admission of the newly activated ONUs for which it opens a quiet window and performs ranging with equalization delay calculation.

8.5 Typical practice of fast protection switchover mechanisms and viability analysis

8.5.1 Pre-ranging

8.5.1.1 Transceivers in the working and backup OLTs

The transceiver in the working OLT is configured to be able to transmit and receive data, and the transceiver in the backup OLT is configured to operate in the receive-mode only, i.e., its receive path is fully enabled while the transmit path is disabled either completely or partially, leaving only the laser in the disabled state to prevent generation of any spontaneous noise.

8.5.1.2 Pre-ranging time points

Pre-ranging can be processed during ONU activation and when the ONU is in the O5 state. Thus, the requisite delay (T_{rd}) referred to above could be PrD pre-assigned by the working OLT during the ONU activation procedure or EqD assigned by the working OLT after the ranging process is completed.

8.5.1.3 Calculation of the backup path EqD

Assuming that Equation (2) is used for calculation of EqD_p, there are a few possible approaches to calculate EqD_p.

1) The backup OLT transmits TP_3 to the working OLT and the working OLT calculates the backup path EqD_p, which is delivered to the backup OLT and the target ONU.

2) The working OLT transmits TP_2 and EqD_m to the backup OLT and the backup OLT calculates EqD_p, which is transmitted to the working OLT and further transmitted to the target ONU by the working OLT.

3) The working OLT transmits TP_2 and EqD_m to the EMS/NMS, the backup OLT transmits TP_3 to the EMS/NMS, and the EMS/NMS calculates EqD_p, which is transmitted to the backup and working OLTs and further transmitted to the target ONU by the working OLT.

Option 1) is recommended as the typical practice. TP_3, the reception time of *Serial_Number_ONU* PLOAMu message in the backup OLT, is sent to the working OLT via a pre-defined communication channel (or alternatively via the NMS/EMS) for calculation of EqD_p. Note that there is already a dedicated bit in the *Ranging_Time* PLOAMd message structure that indicates whether the delivered EqD is for working or backup paths. In this way, no changes to the existing

PLOAM messages are needed to accomplish this functionality. Therefore, the target ONU can store EqD values for both working and backup paths separately.

When TP_3 is received, the working OLT calculates EqD_p for the backup path using Equation (2). It is assumed that the propagation delays in downstream and upstream channels are approximately equal and they do not change between subsequent ranging events. The EqD value is not sensitive to the difference in propagation delay between upstream and downstream wavelength and the guard time is tolerant of such a difference.

Note that due to different refractive indexes for the downstream and upstream wavelengths, there might be a minor difference between the downstream and upstream propagation delays. The factor ($TP_3 - TP_2$) used in the equations above denotes the difference between upstream propagation delays for the main (primary) and protection paths.

In order to properly reflect the difference in propagation delay due to different refractive indexes for the downstream and upstream wavelengths, it is necessary to introduce a correction coefficient *C*, thus making Equation (2) take the following form (see Equation (3)). The value of this correction coefficient can be calculated as defined in Equation (4), where n_D and n_U represent the downstream and upstream channel refractive indices for the deployed SMF, respectively. The resulting Equation (5) provides the final relationship between the protection and main (primary) path equalization delay.

$$EqD_p = EqD_m - (1 + C) \times (TP_3 - TP_2) \quad (3)$$

$$C = n_D/n_U \quad (4)$$

$$EqD_p = EqD_m - (n_D + n_U)/n_U \times (TP_3 - TP_2) \quad (5)$$

In Equations (1) to (5), RTD_{max}, which denotes the maximum RTD value between the OLT and the farthest ONU, could be considered the same for both the working and backup OLTs. However, it is also possible for the working and backup OLTs to use different values of RTD_{max}. In Equations (3) and (5), EqD_p is calculated based on RTD_{max} of the working OLT and should be recalculated based on RTD_{max} of the backup OLT, as shown in Equations (6) and (7), in which $RTD_{max(m)}$ denotes the RTD_{max} for the working primary OLT and $RTD_{max(p)}$ denotes the RTD_{max} for the backup OLT.

$$EqD_p = EqD_m - 2 \times (TP_3 - TP_2) - (RTD_{max(m)} - RTD_{max(p)}) \quad (6)$$

$$EqD_p = EqD_m - (n_D + n_U)/ n_U \times (TP_3 - TP_2) - (RTD_{max(m)} - RTD_{max(p)}) \quad (7)$$

8.5.1.4 Time clock in the backup OLTs

The clock in the backup OLT should be synchronized with the clock in the working OLT. If the two OLTs are in the same rack, time synchronization could be achieved by existing and well-known mechanisms, e.g., hardware TDM connection between two OLTs, etc. If they are geographically distributed, time synchronization could be achieved by the methods shown in Table 3.

Table 3 – Inaccuracy of clock transfer between primary and backup OLT in different variants

	Time synchronization		
	Scenario 1: **There is a dedicated communication path between OLTs**	**Scenario 2:** **OLTs are both connected to a convergence device[a)] (e.g., BNG)**	**Scenario 3:** **OLTs are managed by the same EMS/NMS**
Geographically distributed	OLTs are time-synchronized with each other via [b-IEEE 1588]	OLTs are time-synchronized with the BNG via [b-IEEE 1588]	OLTs are time-synchronized with the EMS/NMS via [b-IEEE 1588]
Inaccuracy between two synchronized OLT clocks	Δ	2 × Δ	2 × Δ
Inaccuracy of the calculation of backup EqD with Equation (5)	2 × Δ	4 × Δ	4 × Δ

a) A "convergence device" is the device connected to the north interface of OLTs. For reference, see Figure 1 in [b-Broadband Forum]. A convergence device is also referred to as a BNG.

NOTE – Δ means inaccuracy of time synchronization via [b-IEEE 1588], the range of which could be on the order of sub-microseconds and is the same for all the EqDs of the ONUs.

Based on the table above, in scenario 1, time synchronization is performed between the working and backup OLTs, so the inaccuracy between the time clocks in the two OLTs is Δ, and the inaccuracy of EqD_p in Equation (2) is doubled to 2 × Δ since 2 × (TP_3 − TP_2) is used. In scenario 2, the time clocks in the working and backup OLTs are both synchronized to a time clock operating in the BNG, the inaccuracies of which are both equal to Δ and the inaccuracy between the time clocks in the working and backup OLTs are 2 × Δ. The inaccuracy of EqD_p in Equation (2) is then doubled to 4 × Δ since 2 × (TP_3 − TP_2) is used. The inaccuracy calculation in scenario 3 is just like that in scenario 2. Therefore, the maximum inaccuracy of the calculation of backup EqD by Equation (2) is about 4 microseconds (if $\Delta \approx 1 \mu s$), which can be tolerated to the EqDs.

8.5.1.5 Lifecycle of the ranged backup path EqD

The measured EqD on the standby link may not be valid after some time, since temperature changes may result with adjustments of the EqD of the ONUs according to the drift control process. And typically the change of the EqD is due to the accumulated effect of temperature changes in the feeder fibre and the drop fibre. However, from observation of the real PON network, EqD adjustment will not be triggered very often if the ODN is stable. For pre-ranging, the backup path EqD can also be measured or updated with a specified interval during the ONU's operational state to observe the RTT continuously, and to mitigate the drift accumulation on the path.

There are a couple of mechanisms to update the backup path EqDs.

(1) The backup path EqDs are updated when the working path EqDs need to be updated.

(2) The backup path EqDs are periodically updated with a specified interval (e.g., every hour).

(3) The backup path EqDs are updated on the command from the EMS/NMS (again, with the frequency defined by the management system, administrator or some external watchdogs).

Given that the update mechanism can be autonomous, the problem with the backup path EqD drift is considered as resolved provided that at least three mechanisms exist to ensure that the backup path EqD is updated periodically.

8.5.1.6 Effectiveness

The pre-ranging method can be executed during the normal ONU working state. The EqD for the backup path can be set or updated before protection has taken place. Hence the backup OLT can bring the ONU back to service without a re-ranging procedure, saving time during protection switchover.

8.5.1.7 Standardization compliance

There is no new requirement to standardize compliance of the ONU and working OLT, but there is an enhanced requirement to support the pre-ranging mechanism for backup OLT implementation beyond GPON or XG-PON1 standardization.

8.5.2 Limited ranging

8.5.2.1 Activities at the OLT side

Figure 13 illustrates the sequence of activities as the OLT operates during the fast switchover period.

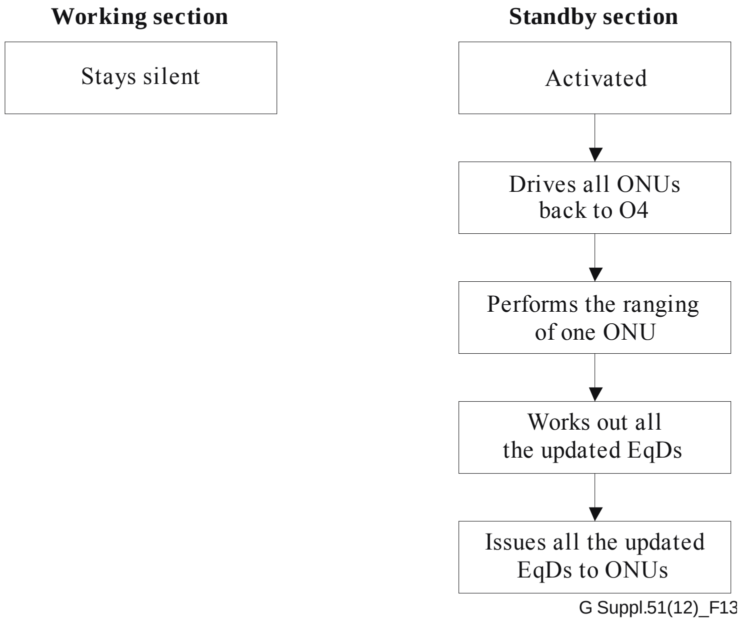

Figure 13 – Activities at the OLT side

8.5.2.2 Activities at the ONU side

Figure 14 illustrates the sequence of activities as the ONU operates during the switchover period.

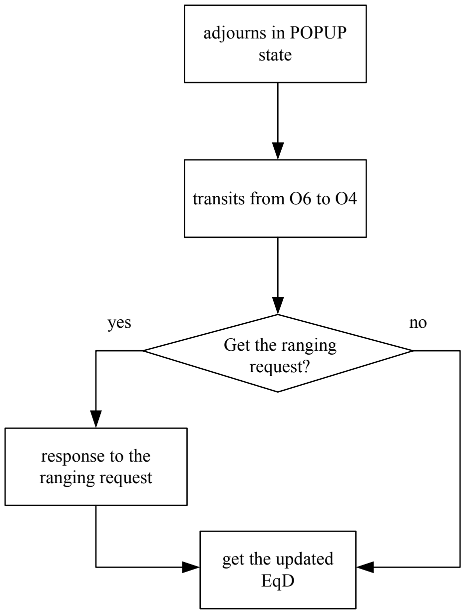

Figure 14 – Activities at the ONU side

8.5.2.3 EqD accuracy

In most of the cases, the accuracy of this method is sufficient to ensure that the ONUs can operate again successfully. In the worst case, its inaccuracy could be 3 times the original GPON ranging inherit inaccuracy, which might present a problem. However, for all the existing systems, the performance depends on the OLTs and most of the OLT implementations can deal with this level of inaccuracy quite well.

8.5.2.4 Fibre propagation delay

For a typical GPON upstream waveband, the biggest refraction index difference is 0.0000457 among this 100 nm window. In the worst case, the length difference between the feeder fibre in the working section and that in the standby section could be up to 20 km. This will lead to a 4-bit propagation delay at most. However, this error can be tolerated by the OLT according to [b-ITU-T G.984.3].

8.5.2.5 Effectiveness

The limited ranging method is performed immediately after the protection switch has taken place. The "common transmission time difference" by re-ranging any one of the connected ONUs, instead of completing a ranging process for every ONU, can save most of the time spent in the O4 state after protection switchover.

8.5.2.6 Standardization compliance

For the limited ranging method, all the activities which are executed between the OLT and ONUs are strictly following the rules defined in the current GPON Recommendation.

For the XG-PON1 system, it is the subject of further study.

8.5.3 Fast ranging

8.5.3.1 Effectiveness

With the fast ranging method, the maximum possible rate that ONUs could be ranged would be 2 per millisecond. A more conservative rate would be one ONU per millisecond. With 32 ONUs, it is theoretically possible to recover the PON within 50 ms. With 64 ONUs or more, this would be difficult or impossible. While simple, this method would be more likely used with Type B PON protection, where service availability does not depend strongly on PON switching time.

8.5.3.2 Standardization compliance

For the fast ranging method, all the activities which are executed between OLT and ONUs are strictly following the rules defined in the current GPON and XG-PON1 Recommendations.

8.5.4 Equalization-delay-agnostic protection switch

8.5.4.1 Effectiveness

With the equalization-delay-agnostic protection switch mechanism in the Type B protection switch, the ONUs can continue to use their old EqDs. The ONU transmissions will still be aligned for the most part (a small variance may occur), but there will be a significant common-mode delay shift. This is equivalent to the protection PON having a different "zero distance equalization delay" (Teqd) value. If the protecting OLT can adapt to this new Teqd value, it can resume ONU communications without reconfiguration. As result, the ONU can save time for the original re-ranging process when the protection switch occurs, and maintain service availability.

8.5.4.2 Standardization compliance

For the re-using EqD values method, all the activities which are executed between the OLT and ONUs are strictly following the rules defined in the current GPON and XG-PON1 Recommendations.

9 Recommended architectures versus use cases

In clause 4 on use cases, some services such as high density PON residential services were considered recommended for protection based on the large number of subscribers experiencing outages if a failure occurred. These residential services were not considered to generally have SLAs requiring 5 '9s' of availability and above. These services would also include the use case of reach extenders if the services are residential. For this level of availability the Type B architecture may be ideal.

For business services 5 '9s' is considered essential, while better availability may be desired. These depend on the SLAs negotiated between the operator and subscriber. For the highest level of availability only Type C may be capable of achieving the levels required.

Ultimately the operator must make an estimate of the overall service availability, including other network components (servers, back office equipment) in addition to the access equipment, and match this to the SLAs the operator will be expected to meet.

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