OTDR measurements on the last mile

Troubleshooting GPON and XGS-PON errors

In Germany as well, fibre optic technology is conquering the last mile. New fibre lines are being laid and households and businesses connected at a record pace. In addition, the number of optical fibre links already laid is growing; this, along with the increasing complexity due to diverse technologies and errors during rollout, is leading to more and more disruptions.

Furthermore, fibre connections are also showing signs of ageing, often depending on how and when they were installed. After all, it has been almost 10 years since the wide-area construction of optical fibre networks commenced in Germany in 2013. Although manufacturers often claim service lives of over 20 years, these claims are frequently only valid under laboratory conditions. Thus, the material used, the temperature and the laying conditions all play an important role, in addition to the pure in-service time. Tension and pressure in particular – whether inflicted during installation or due to changing substrate conditions over time – alter the transmission properties of fibre optics lines. This is the reason why they should be laid in a helical pattern, for example, which ensures that they have a certain "reserve". Tension on a fibre optics line can have negative effects similar to macro bends or plug connections that do not seal properly, which increasingly become a problem over the years due to dirt and moisture.

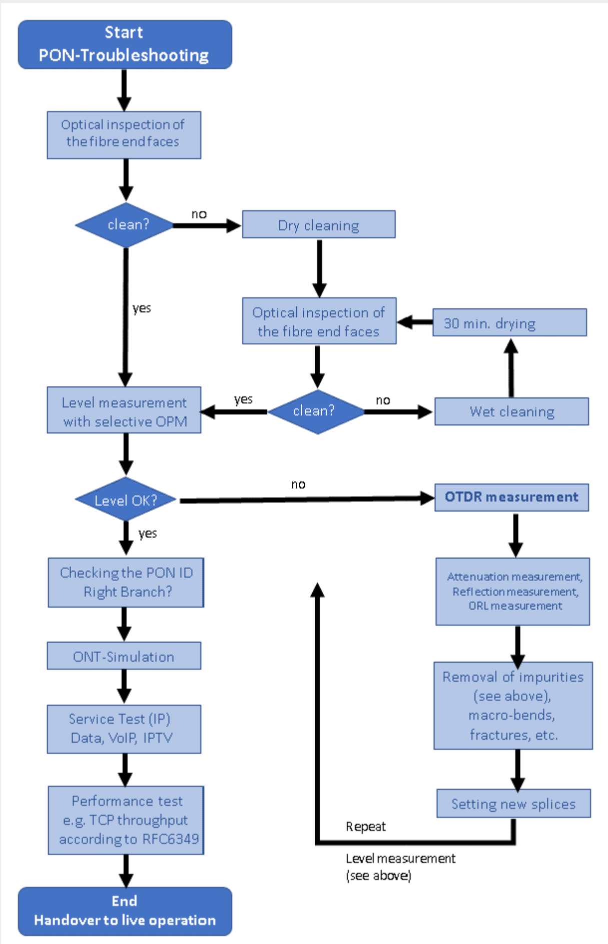

Figure 1: The following procedure is considered best practice for PON troubleshooting.

These are precisely the problems that frequently require the skills of a well-equipped technician.

What can a technician achieve on site?

Obviously, the first priority when working on fibre optic lines is cleanliness. The largest proportion of problems with fibre optic connections is attributable to contaminated connectors. Perhaps the work was not performed properly during the rollout, or the problems only arose later (see above).

It is therefore strongly recommended to proceed as follows for PON troubleshooting (see Fig. 1).

Of course, people naturally seek to optimise their processes and workflows, and consequently often tend to omit one step or another to save time and money. In this case, they are most likely to skip on the last step. Technicians are equipped with inspection and cleaning tools and, over the last few years, with optical power meters as well, but when these confirm a poor level, the correct next step can often prove expensive.

It would therefore be ideal if the technician on site could immediately carry out OTDR troubleshooting. As mentioned above, excavation is truly needed to find the fault in only the very rarest of cases; in most situations, specialist knowledge and the right measuring and testing equipment are sufficient.

One of the few manufacturers to offer instruments with such capabilities is intec GmbH from Lüdenscheid, Germany, which launched the ARGUS® 300, a multifunction tester concept, two years ago. This instrument allows all the above-mentioned test steps to be carried out and logged using a single compact device.

Is all OTDR equal – what is special about the last mile?

The largest proportion of fibre connections rolled out on the last mile are passive optical networks, or PONs. Currently, millions of

GESELLSCHAFT FÜR INFORMATIONSTECHNIK mbH customers in Europe are already connected via GPON accesses (ITU-T G.984.3); at the same time, many countries are beginning to roll out XGS-PON (ITU-T G.9807.1, symmetrical 10 gigabit PON) over the same fibre links; in many places, a hybrid or mixed operation is emerging. The trend in Germany is expected to go in this direction as well.

PONs are always single-mode fibres with a relatively short line length, theoretically up to max. 20 km, in practice often much shorter. An OTDR instrument should take this into account by enabling small pulse widths and dead zones (see below).

The criterion is the wavelengths that the OTDR should be able to cover. GPON uses 1310 nm (up) and 1490 nm (down), XGS-PON uses 1270 nm (up) and 1577 nm (down). Also, many active fibre connections such as Active Ethernet or Active Optical Network (AON), which are often used in FTTH connections by some city network operators, run on single-mode fibres at exactly these wavelengths and similar line lengths.

An OTDR suitable for PON troubleshooting should therefore support at least two wavelengths: one of the above-mentioned commonly used wavelengths (e.g. 1310 nm) if the network or the section to be measured is out of service; and a second wavelength that allows interference-free in-service measurements, which is particularly important if the technician does not have access to both ends of the optical fibre. The latter should have the greatest possible separation from the live wavelengths; the maintenance wavelength 1650 nm is a good choice here. The technician then has exactly one wavelength in the second optical window and one in the third optical window. Optical windows are wavelength ranges that are particularly suitable for data transmission, as certain ranges are better suited and some less so due to the material.

Other measuring instruments are a better choice for backbone and long-distance links with multimode fibres and speeds above 10 Gbit/s. However, this often involves massive network problems with many affected customers – this cannot and should not be covered by an OTDR for access troubleshooting.

An OTDR for the access sector simply and rapidly localise problems from the individual subscriber to the splitter, rarely beyond. If the problem is behind the splitter, i.e. further towards the backbone, the problem usually affects the entire PON branch and thus multiple subscribers at the same time.

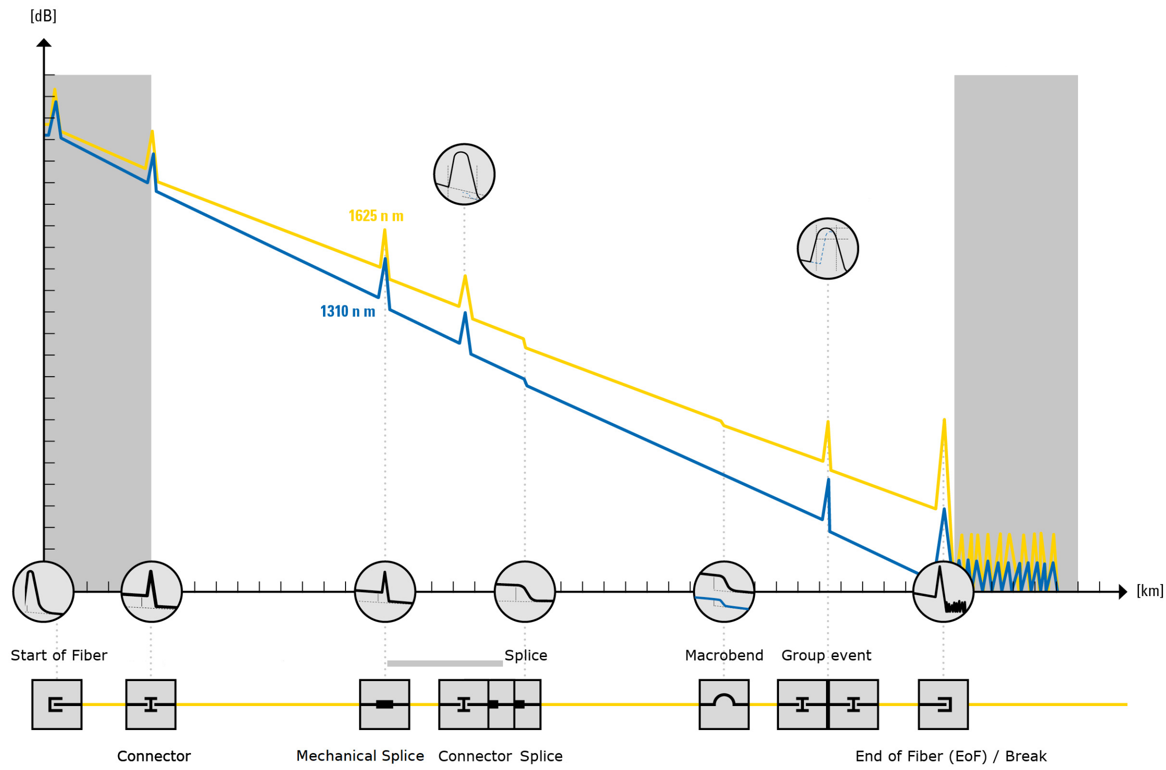

Figure 2: Example events mapped on an OTDR trace.

What does an OTDR actually do?

An OTDR measures the line attenuation and event attenuation and can determine the line length, splices and connectors from information this together with the propagation time of the reflected pulse (see Fig. 2). If the OTDR also has two wavelengths, it is even possible to detect and localise a bending radius violation (macrobend) by measuring with both (e.g. in an auto mode).

For this purpose, an OTDR generates a pulse using a laser diode that is coupled into an optical fibre as an optical signal via a bidirectional coupler. Via the same coupler, it then analyses the pulse components reflected back by Rayleigh scattering (attenuation) and Fresnel reflection (localisation).

Electromagnetic waves, including light, are scattered in all directions by tiny molecules (Rayleigh scattering), because the material of a glass fibre is not ideal but rather contains irregularities. This is due to the manufacturing process and the quality of the materials used, among other factors. These impurities in turn cause unwanted fluctuations in the index of refraction (IoR), which describes the ratio of the speed of light in a vacuum to the speed of propagation in the fibre material.

A part of the light is also scattered back to the OTDR; the measurement of its intensity (backscatter measurement) results in the optical return loss (ORL), which permits conclusions as to the fibre length, the attenuation per kilometre as well as the insertion loss (IL) and reflectance at events. We can say that the greater the backscatter, the greater the attenuation on the line.

Fresnel reflection plays a role in localising events. In fibre optics technology, the "total" reflection of electromagnetic waves at material transitions due to a refractive index transition occurs primarily at connectors (glass-air-glass). Fibre breaks, the end of an open fibre, contamination or scratches on fibre end surfaces also lead to these effects, known as Fresnel losses. This phenomenon can also reveal a poorly executed splice. The light of a specific wavelength is incident on such an event and is reflected much more strongly and directionally in relation to the Rayleigh scattering.

The insertion of a precisely defined pulse, e.g. with a duration of exactly 10 ns, makes it possible to detect the reflection of the pulse at an event and thus to measure its transit time (outward and return path). With this measured time and the knowledge of the refractive index of the fibre in question, the distance of the event from the OTDR instrument can be determined extremely precisely.

What should we look for when choosing an OTDR instrument?

Dynamic range, insertion level and averaging

In addition to the variable pulse width (see below) and the insertion level, the available dynamic range represents a pivotal quality feature. The pulse width and transmission level together determine how much energy can be put into the pulse and thus onto the line. The dynamic range describes how much the transmitted pulses can be attenuated by distance and events and still be recognised after scattering and reflection. It can also be described as the sensitivity of the OTDR.

The instrument permits users to define a preferred averaging time to increase the dynamic range somewhat through repeated measurement. When the period over which the measuring instrument takes multiple measurements and averages the results, e.g. 60 seconds, is known, this results in an improved signal-to-noise ratio and thus, ultimately, better results.

However, for an OTDR instrument used primarily on PONs, a dynamic range of e.g. 20 dB is entirely sufficient. In combination with a high insertion level and a pulse width of e.g. 100 ns, it is possible – depending on the quality of the fibre and the number of events – to draw conclusions about distances of several kilometres (see above). Certainly, units with much better dynamic ranges and higher averaging times are also available, but for short distances to and from accesses, these represent a substantial, unnecessary additional expense.

When working with the OTDR instrument, ideal insertion conditions are significantly more important. If these are poor, e.g. due to a defective connector, scratches or contamination, this reduces the intensity of the pulse and thus the dynamic range and, as a consequence, the accuracy of the measurement, right from the start. That is why the inspection and cleaning mentioned at the outset are of great importance.

Pulse width and dead zones

The most important criterion is the localisation resolution, i.e. how accurately can OTDR provide line lengths or distances to events. In this connection, we can say that the narrower the pulse, the better the resolution: in theory, accuracies of up to 1 m can be achieved at 10 ns. Of course, deviations and uncertainties still arise due to the length of the line section, the measurement itself, the temperature and other influences, but these are no longer so significant.

Therefore, it is important to ensure that the pulse width is adjustable within certain parameters. At first glance, one might be inclined to always choose the highest value, but beware: the wider the pulse, the more likely it is to conceal closely spaced events. As a rule of thumb, one can say that two events can be distinguished if they are at least half a pulse width apart. So if you expect "many" events when measuring short lines, it is advisable to choose a shorter pulse. It should also be possible to configure the instrument for the expected fibre optic length, as this determines the transit time of the pulse on the line and thus has a direct influence on the dead zone.

There are two types of dead zone. Firstly, there is the event dead zone, which specifies the distance at which two events can be distinguished from each other (see above); and the attenuation dead zone, which determines the minimum distance between two events such that the attenuation can still be determined precisely - both together comprise the so-called total dead zone. This is usually specified for very short pulse widths (e.g. 10 ns) and should be in the range of a few metres.

The accuracy of the attenuation measurement, the linearity – whether of that of the distance or the the event — is another important selection criterion; a deviation of ±0.05 dB/dB is entirely sufficient for use in the access sector.

Overall, however, the accuracy is determined by the number of recorded data points, i.e. in how many individual values the measuring instrument can store for the measurement. The more data points available, the higher the resolution and accuracy in the end. For the application described above, 100,000 data points are sufficient. 300,000 data points is ideal, especially for longer distances.

As with TDR measurements on copper lines, it is also important to know the details of the fibre to be measured when performing OTDR measurements. The instrument should thus enable you to enter important fibre parameters in order to obtain the most accurate results. These include first and foremost the index of refraction, (IoR), the Rayleigh backscattering coefficient (BC) and the attenuation coefficient (ACI).

How can the OTDR instrument support the user?

Instruments with an auto mode perform many tasks fully automatically and are recommended especially for beginners. Tests with different wavelengths and pulse widths are carried out automatically and the results are conveniently displayed in an event table with the help of symbols, length and distance information. Ideally, this even includes pass/fail evaluation, and a good OTDR tester should permit definition of the corresponding limit values for the splice, macro bend and connector events. Some instruments even come with a pre-defined assessment according to ITU-T G.671 or TIA 568.3-D, which of course makes servicing a little easier, but the values cannot then be customised to your own quality requirements – which may be higher.

However, since every novice will have gained sufficient experience by some point, it makes a lot of sense to ensure that the instrument also comes with a manual mode with dedicated OTDR graphs and a real-time mode that enables users to reliably detect rapidly changing events as well. With auto modes, this is more or less left to chance.

Leading and trailing fibre cables, port saver

Regardless of whether you are a novice or an expert, whether you are using auto mode or real-time measurement, never troubleshoot without using leading and trailing fibre cables and make sure that you are offered them with when you purchase an OTDR instrument. Often it is precisely the connector of the fibre to be measured that causes the greatest problems; wear and contamination are the most common and severe faults here. If one were to plug the fibre to be measured directly into the OTDR instrument, it would not be possible to assess the influence of the connector on the overall line, even with narrow pulses, since the event dead zone (see above) is greater than zero, but the connector is virtually at zero. By inserting a leading fibre line of e.g. 1000 m, we can ensure an accurate evaluation this event.

A similar effect occurs at the end of fibre (EoF): If the last connector of the fibre to be measured is open, there is a complete reflection at the end of the fibre – making it impossible to draw conclusions about the quality of the downstream connector. Whether it is precisely this last connector at the end of the fibre that is perhaps the actual problem the technician was called out to fix, on account to contamination, cannot be determined. Only the use of a trailing fibre makes the last open connector to be evaluated a fully-fledged connector with measurable attenuation.

Leading and trailing fibres should always be of the same fibre type and longer than the own attenuation dead zone. Be sure to use high quality leading and trailing fibres; the connectors in an OTDR measurement must always be of the highest quality and they should not wear out quickly, if at all possible. A port saver should therefore be included in the scope of delivery. It can be connected between the OTDR tester and the leading fibre to protect both the actual connector of the measuring instrument and the leading fibre and can be easily and cheaply replaced after a few 100 mating cycles.

Measurement logging:

When performing contract work, e.g. for a network operator or for your own documentation, it is also important to be able to export all data obtained from the measuring instrument completely for later analyses. The device should be able to export all data points to a Standard OTDR Record (SOR) file. Free SOR viewers then enable an in-depth analysis down to individual data points.

When choosing optical test and measurement equipment, carefully consider the sector in which you wish to use your instrument, so that you have exactly the right solution at hand when problems arise. The use of a multifunction tester can save a lot of time, as it enables a prompt initial assessment: Especially in the case of "minor" problems (contamination, contact problems, etc.), it is then not necessary to wait for the expert!

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