MODERN CHALLENGES IN THE MAINTENANCE OF FIXED ACCESS TELECOMMUNICATION NETWORKS

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ABSTRACT

Fixed access telecommunication networks built from symmetrical copper pair cables have been transmitting only low-band services (voice, fax, low-rate data …) during years. Wide range of network parameters values has been sufficient in order to make the networks suitable for these services. However, with the introduction of DSL (Digital Subscriber Line) and triple-play services, especially IPTV (Internet Protocol TV) as highly required service, existing access networks performances need to satisfy very strong requirements, such produce an amazing challenge for network's maintenance staff. This paper describes some methods for monitoring the quality of old-fashion access networks in a recent condition, as well as the actions to be taken in order to reach and preserve sufficient quality of such infrastructure or bring it in a condition that enables the delivery of highly demanding triple-play services.

1. INTRODUCTION

The largest number of existing telecom operators in Europe for the delivery of triple-play services (voice, data and video) use mostly xDSL (x Digital Subscriber Line) lines, and to a lesser extent FTTx (Fiber to the x), where VDSL (Very High Bit Rate Digital Subscriber Line) lines dominate. As a medium of signal transmission for DSL lines and VDSL we use symmetrical copper pairs, which are the basic elements of copper telecommunications cables. Over 80% of triple-play services in Europe are supplied through different varieties of DSL lines, such as ADSL2 + (Asymmetric DSL), VDSL and VDSL2 lines [1].

In most cases, these symmetrical copper pairs, i.e. telecommunication cables are installed many decades ago. Almost the entire time they were transmitting only analog POTS (Plain Old Telephone Service) services. These analog services are highly immune to the possibility of significant degradation of initial values of parameters that describe the quality of symmetrical copper pairs. However, when it comes to triple-play services, especially IPTV (Internet Protocol TV) as far the most demanding service, then these services require a significantly better quality of symmetrical copper pairs [2]. These modern services require that the quality of symmetrical copper pairs and telecommunication cables, i.e. access networks made of these cables, come close to the quality that these elements had when were first installed [3].

In this regard, maintaining the infrastructure of copper access networks at the present time when triple-play services dominate is much more complex than it was in the time of dominance of POTS service. As the current triple-play services are immeasurably more complex and provide much more to the user, so is the maintenance of access networks immeasurably more complex.

2. SIMPLIFIED STRUCTURAL MODEL OF ACCESS NETWORK

Figure 1 shows a simple model of access network made of cables with symmetrical copper pairs.

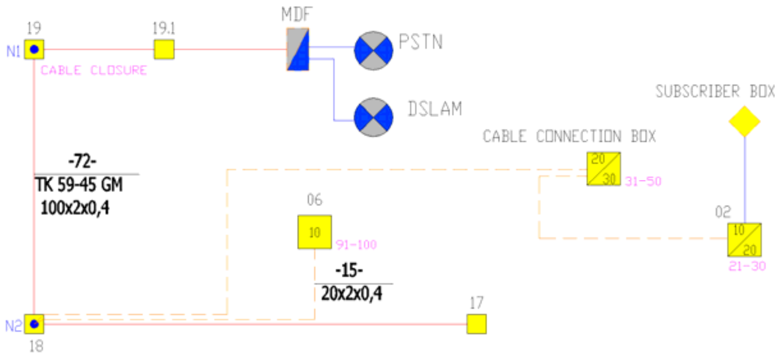

Figure 1. A simple model of an access network

From this model it can be seen that a fixed access network consists of a number of basic elements, namely: MDF (the main distribution frame), cable joints, distribution points (e.g. cable connection box, subscriber box, subscriber box and a plug in the user's facility) and cable segments. In all these points, except in cable segments, it comes to cross connections of cables, i.e. copper pairs. All these places represent a kind of discontinuity of copper pairs and cables, i.e. their conductors, as well as insulating elements and sheaths.

Basic structural elements of telecommunication cables are symmetric copper pair, core, core wrapping, sheath and armature as shown in Figure 2. Sheaths are intended to hermetically seal cables against penetration of moisture and chemical solutions, mechanical protection of the core and protection from foreign electromagnetic fields. They are made of an alloy of lead, aluminium, steel, polyethylene, polyvinyl chloride, etc.. Armature protects the core from mechanical damage and from atmospheric discharges and the impact of foreign electromagnetic fields. It is made of steel strips or wires.

The core of telecommunication cables is the most important structural element of cables. All electromagnetic processes by which we transfer electrical signals occur in the core. It consists of copper pairs as electrical lines that form circuits, independent from each other. Basic uninsulated structural element of core is a conductor that is made of electrolytic copper. Copper conductor is cylindrical, uniformly drawn, soft annealed wire with homogeneous consistency without cracks and impurities. It is important to emphasize the importance of cylindricity being the most ideal. Two conductors make one pair.
In addition, materials for insulating the conductor in a pair must meet the requirements in terms of mechanical, thermal and chemical characteristics. Individually isolated and stranded conductors must withstand the mechanical stresses during production of the cable, as well as during installation and operation. From the standpoint of their geometry, insulating material should have the same thickness at each point of pair and conductor. The homogeneity of the composition is very important. Insulation material has a significant impact on the mutual influences of adjacent pair

Picture 2. Copper telecommunication cable

It is important to mention that, in order to make the electromagnetic coupling between the symmetrical copper pairs smaller, they are threaded with the correct twist pitch, which is a very important feature of copper pairs.

3. SYMMETRICAL COPPER PAIR PARAMETERS

For the purpose of better physical understanding of the symmetrical copper pairs as electric line, the same can be expressed and viewed using electrical quantities that we call primary parameters: series resistance (R'), shunt conductivity (G'), series inductance (L') and shunt capacitance (C').

Series resistance (R') of a symmetric pair depends on the metal of which symmetrical pair conductors are made, cable diameters, ambient temperature and frequency of current flowing through the conductor. Series resistance directly increases with decreasing diameter of the conductor and with increasing the length of the conductor.

Mutually insulated conductors of symmetrical pair never have perfect insulation, i.e. between the two conductors occurs electrical current which, in essence, characterizes imperfect wire insulation. Shunt conductivity (G') of isolation increases with increasing frequency.
Series inductance (L') is a consequence of the presence of one electric line conductor in its own electromagnetic field and the external influence of other conductors.
Conductors of a symmetrical pair behave like capacitor plates with dielectric between them. This capacitor is characterized by shunt capacitance of symmetric pair (C'), also referred to as working capacity of symmetric pair. The size of the shunt capacitance is significantly affected primarily by geometric arrangement of the conductors and the type of wire insulation. Shunt capacitance is reduced by increasing the distance between conductors, reducing the surface of the conductor, increasing the permittivity and increasing the moisture in the insulation.

In addition to previously described four primary parameters of symmetric copper pairs, secondary parameters are defined, which depend on the frequency of the signal that is transmitted over copper pairs: propagation constant and characteristic impedance.
Regardless of what kind of services symmetrical copper pair is analysed for, i.e. when it comes to simple POTS service, or in the case of very demanding triple-play services on VDSL and ADSL 2+ lines that transmit bit rates of tens or hundreds of Mb/s, copper pair as a medium of transmission of electrical signals is described with these above mentioned six parameters [3].
In the production of cables the values of primary and secondary parameters that produced cables must meet in order to transmit the desired services are defined. Regardless of whether some cables are produced at the time of existence of only POTS service, they are able to transmit xDSL line signals without problems with bit rates of tens and hundreds of Mb/s. Of course, provided that they did not significantly change their primary and secondary parameters during the period of exploitation. At the same time certain requirements must be met in terms of required length, because the length of the cable increases the weakening of

lines. And with the increase in line weakening, bit rates that this line can transfer decrease.

4. PHENOMENA THAT DEGRADE THE QUALITY OF COPPER CABLES

In practice it is not possible to achieve ideal symmetry and avoid mutual influences of cable conductors. Mistakes during installation, various external damage during exploitation, small distance between conductors, unevenness of twist rate, imperfections of insulation and many other factors distort the symmetry of the cable. For longer cables, due to mentioned variations in certain points of cables very different malfunctions and interferences appear that may interfere with the transmission of signals, and thus affect the quality of services delivered.

Malfunction is a result of permanent cancellation or change of one or more elements of the telecommunication cable or pair, whereby it comes to major or minor changes of one or more primary parameters of copper pairs. There are several types of malfunctions. According to the causes that lead to them, malfunctions can be divided as follows:

- malfunctions due to corrosion,
- malfunctions due to vibrations (damages of the cable sheath due to periodic shakes of the cable, when it is set on a bridge or near roads, where their influence on the static cable is expressed)
- malfunctions due to aggressive actions (construction in the immediate vicinity, atmospheric discharge, landslides, floods, war destruction, earthquakes) and
- malfunctions due to biological effects (rodents, insects, roots of trees or other vegetation).

According to the physical value that characterizes malfunctions, they can be classified as:

- Resistive malfunctions: This is the most common types of malfunctions. According to the direction we classify them into transversal (contacts of conductor and sheath, mutual contact of two conductors in the pair, mutual contact of more conductors in the cable with simultaneous contacts with sheath of cables) and longitudinal malfunctions (discontinuities of conductors, significantly higher contact resistance on contacts, discontinuities of sheath). According to the distribution of galvanic malfunctions, we classify them into concentrated and distributed malfunctions.
- Capacitive malfunctions: They occur as a result of capacitive asymmetry, due to which it comes to the occurrence of crosstalk via capacitive coupling. All capacitive malfunctions are transversal. These malfunctions occur at the beginning of the penetration of water and moisture in the cable. This type of malfunction also include split pairs. This is a common error in installation and mounting the cables, when conductors of different pairs in the cable are connected by mistake.
- Inductive malfunctions: These are longitudinal malfunctions that occur due to inductive asymmetry, which through the inductive couplings leads to asymmetry. These malfunctions usually occur due to the disruption of the screened cable sheath.

An interference on DSL local loop implies an occurrence on the observed copper pair which interferes the useful signal by undesirable signal whereby the interfering signal superimposes on the useful signal. In addition, there may or may not be an easily measurable and visible malfunction on the observed pair. There are several types of interferences.
An unwanted signal can be useful signal from another, adjacent copper pair, that transmits only POTS signal or copper pair that transmits xDSL signal which is transmitted to the observed pair by electromagnetic radiation. On xDSL lines the biggest problem is the occurrence of FEXT (Far End Crosstalk), Figure 3. Although in one cable there may be

hundreds of different copper pairs, the occurrence of FEXT crosstalk is most dominantly affected by one or possibly two adjacent pairs of the same cable [4].

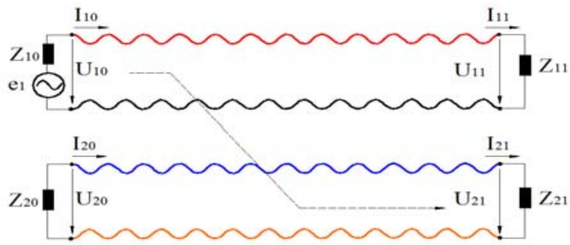

Figure 3. FEXT (Far End Crosstalk)

An interference can also be caused by any other electromagnetic transmission, i.e. induction of unwanted electrical signal on the observed copper pair, which comes from the outside of the observed cable. In case of interference it does not come to a complete standstill of transfer of DSL signal on the observed pair. But the presence of foreign unwanted electrical signal can lead to the emergence of line faults on the interfered line.

Looking at the position of the cable, practice has shown that by far the largest number of causes of malfunctions, as well as interferences, occurs in concentrated points in space that we have marked as the basic elements of the access network in Figure 1. These points are far "the weakest links" on cables and pairs. In these elements there is a disruption of the physical continuity of copper pairs and their insulation materials and sheathes.

The most common causes of malfunctions are moisture penetration into connectors on cables, or through damaged sheaths. Then, the influence of moisture or dust from the environment on the contacts of pairs in the cable connection boxes, subscriber boxes, cable splitters, or plugs. Frequent causes of interferences can also be manual errors when installing cables, such as making poor contacts on conductors, or the so-called decoupling pairs. Also, a significant number of failures is a result of physical damage of cables due to illicit and illegal construction, which is particularly evident in recent years in Bosnia and Herzegovina.

Regarding occurrences of interference, if they are not caused by some small defects, interferences may occur due to occurrence of strong external sources of electromagnetic radiation (high voltage cables, high-power electric machines, atmospheric discharge and so on.) near the cables, after their installation. In fact, if it is known, before installing cables, that they will be close to sources of strong electromagnetic radiation, then in such conditions cables that have additional protection against these impacts are installed.

5. MAINTENANCE OF ACCESS NETWORKS

The main purpose of maintaining access networks is preventing occurrences that degrade the quality of the access network, i.e. all those occurrences that cause malfunctions and interferences, or removal of these occurrences, when they already happen. In this regard, we differe:

- Preventive maintenance: its task is to prevent the occurrence of malfunctions and disturbances,
- Corrective maintenance: its task is to remove malfunctions and interferences as soon as possible.

Preventive maintenance includes mechanisms for automatic control of the condition of certain segments of the network. On older cable types, i.e. the cables with air-paper insulation mechanism of gas control of condition of cables enabled timely detection of cable damages and their protection in terms of less moisture.
An evolution of this mechanism on cables with thermoplastic insulation filled with gel is the installation of moisture sensors in the extensions of cables. Preventive maintenance includes periodic visits and examination of certain elements of network to occurrences that are visually noticeable (installation threats, corrosion on the visible contact points such as: cable connection boxes, subscriber boxes, etc). Preventive maintenance includes periodic measurements of electrical parameters of copper pairs and cables.

However, preventive maintenance in modern times increasingly takes a back seat in relation to the interventional regular maintenance. The reasons for this were several:

- It is much cheaper to create mechanisms for the prompt response during interventional maintenance, than spending hours, funds and other resources in advance, in order to forestall something that often will not happen.
- During the market competition, customer migration between operators is very pronounced. Thus the need to spend more of employees' working hours on the individual requirements of the users themselves to activate new and additional services, rather than on the infrastructure over which their services are delivered. Infrastructure comes into focus only when it is necessary (occurrence of failures, malfunctions, a clear threats on it and similar.).

For testing the quality of symmetrical copper wires and cables made of them when performing maintenance, we do not get reliable information about their quality in practice by direct measurements of primary and secondary parameters, but by measuring a large number of electrical parameters of copper pairs [3], and parameters of physical layer of xDSL transceiver [5].

The electrical parameters of symmetrical copper pairs that need to be measured are:

- foreign voltage (DC and AC),
- insulation resistance of copper pair,
- DC loop resistance,
- loop length,
- longitudinal balance,
- near end crosstalk (NEXT),
- far end crosstalk (FEXT),
- wideband noise,
- impulse noise,
- impedance of line,
- return loss.

By measuring and knowing these parameters we can reliably know whether the observed copper pairs can become xDSL lines, and determine the approximate bit rate that can be transmitted. But, in order to reliably know if an xDSL line can operate without line errors and with satisfactory QoS (Quality of Service) in the domain in which the xDSL line affects the QoS parameters [2], the parameters of physical layer of xDSL transceiver should be tested.

Some of the parameters of the physical layer that need to be tested are:

- Actual line data rate,
- Maximum achievable rate,
- Output power,
- Signal attenuation,
- SNR (Signal to Noise) margin,
- FEC (Forward Error Correction) codes,
- CV (Code Violation) codes,
- Count of initialization attempts,
- Error seconds (ES),
- Error correction seconds (ECS),
- Severely error seconds (SES).

With knowledge of the electrical parameters and parameters of the physical layer, it is reliably known whether copper cables have sufficient quality in terms of services that they need to transmit. Some copper pairs can quite satisfactorily support some less demanding services, and that cannot support services that demand higher bit rate transmission.

6. MAINTENANCE OF ACCESS NETTWORKS FOR THE PURPOSES OF DELIVERING OF TRIPLE-PLAY SERVICES

Figure 4 shows the evolution of capabilities of copper pairs to transmit signals of high bit rate, of course, with the installation of required active transceiver equipment.

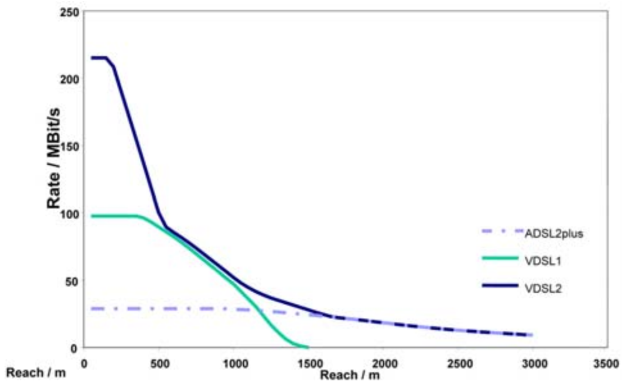

Figure 4. ADSL2+, VDSL and VDSL bit rates compared

It is clearly visible that xDSL lines should be as short as possible, because reduction of length of a line increases its ability to transmit higher bit rates [3]. The increase in achievable bit rates is intended to enable the delivery of highly demanding services: greater number of IPTV channels, HDTV IPTV channels and Internet access at high speeds. Of course, these very demanding services set very strict requirements in terms of quality of copper pairs through which they are delivered [3].

In terms of maintaining such complex services and infrastructure through which services are delivered, and which are very prone to malfunctions and interferences, focus is given to monitoring primarily of those lines that are active and transmit services [5] - [7].

Regarding QoS control [2] mechanisms and mechanisms that control parameters of the physical layer very reliable solutions have existed for a long time [5]. With these solutions it can be reliably determined whether the quality of a certain copper pair is degraded. Considerable progress has been made in terms of solutions for centralized measurement of some, but not all required electrical parameters [6]. The purpose of these electrical measurements is to more reliably determine occurrences on the physical layer that cause malfunctions and interferences, and this should facilitate the detection of causes of malfunctions and interferences. These solutions are implemented in the active equipment that delivers services.

However, in terms of mechanisms for spatial location of malfunctions and interferences significant progress has not been made [4], [8]. The detection of the real causes of malfunctions and interferences, and spatial location of points in the access network in which there are causes of malfunctions and interferences in a significant number of cases is still left to measurements using manual measurement instruments [3]. This implies very often time-ineffective troubleshooting.

4. CONCLUSION

The existing access network infrastructure made of cables with symmetrical copper pairs enables the existing operators to deliver all currently known telecommunication services, as well as those that may occur, with relatively small investments, which are immeasurably lower than building access networks with other transfer media. However, this infrastructure is very prone to malfunctions and interferences that lead to problems in the delivery of triple-play services. In this regard, enormous attention must be given to the effective maintenance of infrastructure of these access networks.

The importance and topicality of this issue is pointed out by dates of adoption of relevant recommendations and technical reports. Many of them have been adopted only few years ago, whereby almost every year new amendments are brought to certain segments of these recommendations.

Current solutions for monitoring the condition of active copper pairs allow highly reliable time-efficient detection of presence of problems in the domain of access networks. However, sufficiently time-effective solutions to the spatial location of points in the access networks in which malfunctions and interferences occur are still not developed. A mitigating factor for the time efficient detection of spatial points with malfunctions and interference is that, when the malfunctions and interferences occur and they occur in most cases in one or possibly several spatial points that we have marked as the most critical in access networks.

5. REFERENCES

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