Journal of International Scientific Publications:
Materials, Methods & Technologies, Volume 5, Part 1
ISSN 1313-2539, Published at: http://www.science-journals.eu

TESTING THE LOCAL-LOOP AND DSL

Pencho Penchev[1], Miroslav Slavov[1]
[1] Technical University of Gabrovo. Hadji Dimitar str.№4, Gabrovo 5300, Bulgaria

Abstract

This paper describe practical methods to detect and repair faults and impairments found in the local-loop telephony cable plant. Although all aspects of telephone cable are discussed an emphasis is placed on preparing cables for the broadband signal of DSL, and looks at the testing elements recommended to support DSL through local-loop qualification and DSL service-confirmation testing.

Key words: Local-loop, testing, xDSL, troubleshooting

1. INTRODUCTION

The traditional telephone network, commonly known as the plain old telephone system (POTS), uses circuit-switched methods to route telephone signals from one destination to another. For the most part, each subscriber is connected to the network with a single pair of twisted wires. Typically these local loops are less than 20 000 feet (6 km) in length. However, some can be as long as 90 000 feet (27 km) in rural areas. Once a subscriber's telephony signals are digitized and carried from city to city and country to country over digital transmission facilities. Currently in the Bulgaria (city Gabrovo, branch of BTC), there are thousand telephone lines, that are routed through circuit switches, of which over hundred are residential. It took over a hundred years and hundreds of millions of levs to build the current telephone network. A large part of the investment has been made in the local-loop plant, in other words, the copper wire between the central office (CO) exchange and the subscriber.

Within the past few years, digital subscriber line (DSL) technology has become popular and is being rapidly deployed. DSL bypasses the bandwidth-limited, circuit-switching infrastructure of the POTS network. In the case of DSL, the copper local loops that carry DSL signals from the subscriber to the central office are terminated into a parallel device called a digital-subscriber loop-access multiplexer (DSLAM). From the DSLAM, the data moves directly to high-speed digital backbone networks that connect to application server such as those found at Internet service providers. In addition, DSLAM may serve as virtual private network (VPN) to corporate users, or may enable other services such as streaming video services. The prime advantage of DSL is that it permits the reuse of the current investment in existing copper, but without dependency on, and limitations of, the central office switch.

2. DIGITAL SUBSCRIBER LINE

DSL is a digital broadband technology that involves sending digital information over a subscriber's line, which is also referred to as the local loop. The applications of DSL involve the transport of high-speed data to residential and business customers.

Compared to regular analog modems (for example, a dial-up, 56 kbps V.92 modem), DSL achieves its higher data transfer rates by utilizing more of the available bandwidth of a local loop. Ordinary telephone service only makes use of a limited amount of bandwidth, up to 3400 Hz. DSL provides between 256 kbps and 100 Mbps. This allows for the simultaneous transmission of high-quality digital voice, data and video.

Despite all of its positive attributes, DSL, like most technologies, is not without flaws. For instance, in order to be eligible for DSL, end users must be located within a certain distance from the central telephone office, otherwise, the signal degradation (attenuation) may be too great such that DSL is either not feasible, the bit rate attainable is not attractive to the customer, or an expensive repeater needs to be added.

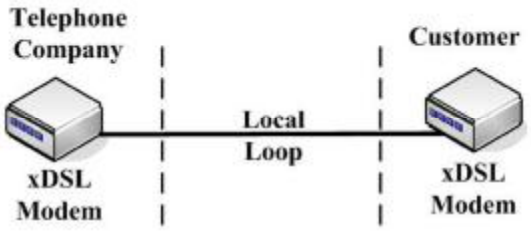


Fig. 1. Basic DSL architecture.

DSL service performance varies due to the following factors:

– The distance between a customer premises and the local telephone company's CO or remote terminal;

– The type and brand of DSL equipment used at both ends of the connection;

– The capacity of the digital backbone that is available to support each DSLAM;

– The number of users that are aggregated to the available digital backbone;

– The behavior of the server community;

– The quality of the local loop between the customer premises and the service provider' CO;

– The proximity of noise sources to the DSL equipment and the local loop;

– The state of the customer premises wiring;

– The state and power of the user's PC and/or routers;

– The condition of the public power feed and grounding.

Distance is an important factor in the delivery of DSL services. The longer the loop, the higher the attenuation and the greater the amount of external noise coupled onto the loop from various sources. Many service providers use only a "best guess" method to determine which subscribers are within their serving area for a particular version of DSL. Businesses are less likely to be denied DSL as there is higher concentration of businesses in urban areas. Telephone company has generally designed her networks in such a way that these areas are well served. On other hand, DSL is relatively new to the residential user. Longer loops are a more common limiting factor in residential DSL delivery.

The "best guess" method is only a partially successful method of eliminating long-loop subscribers since telephone cables are not laid in a straight line. They follow streets, roads, tunnels, cable routes, and rivers. If a telephone company has detailed cable-plant records, these can be used. Unfortunately, cable-plant records, in most cases, have not been kept up to date, or do not include repair information. A more accurate approach to determining the correct distance from the telephone company's serving office is through the method of pre-qualification. Generally, an automatic test system is used to

measure some parameters of each loop in order to determine its length and perhaps its quality. One method that is in common use is time-domain reflectometry (TDR).

If a local loop is properly terminated (i.e., connected to a telephone and DSL modem at the subscriber site), the energy of a TDR pulse may be totally absorbed and not reflected. Telephone companies that rely solely on TDR therefore need to install an automatic loop-disconnect device within the network interface device (NID), a small box attached to the outside of a customer's premises. Alternatively, the telephone company can dispatch personnel to the subscriber's location to run the test (i.e., roll a truck).

Alternatively, the capacitance of the cable can be measured to approximate its length – the longer the cable, the greater the capacitance. Typically, cable has a capacitance of approximately 52 nF per km. Unfortunately, measuring the capacitance of cable is not always an accurate method of determining cable length. The distance between the conductors has an effect on its capacitance. Each type and brand of cable bundle has a unique value of capacitance per kilometer. Some local loops have extra capacitors in order to compensate for longer-length impedance matching. Subscriber-side equipment such as POTS splitters and micro-filters, which are added to enable DSL services, add large amounts of capacitance. The capacitance of bridged taps (also called laterals and multiple appearances) is added to the capacitance of the cable. As is the case for TDR measurements, the local loop needs to be uncoupled from the subscriber's premises, otherwise, the capacitance added by micro-filters, POTS splitters, telephones and modems would need to be taken into account for an accurate measurement. Additional capacitance makes the local loop appear to be much longer than it really is.

3. INTEROPERABILITY OF DSL EQUIPMENT

DSL is slowly becoming a technology that allows subscribers to buy customer premises equipment (CPE) from a number of different manufactures and feel confident that this equipment will be compatible with the network. Despite favorable press about interoperability, the best approach for true DSL interoperability is still to use the same brand of equipment in the CO DSLAM and in the equipment at the customer premises. This ensures maximum interoperability and maximizes data rates.

Installers and maintenance staff use such portable test sets to confirm the connection rates of both asymmetrical (ADSL, ADSL2+, VDSL2) and symmetrical (SHDSL, VDSL2) services. They are also used to troubleshoot the Internet connection through the IP layers.

More and more service providers are now offering video services to their subscribers. These services could be video-on-demand or broadcast television services. Most companies have chosen Internet protocol-based television, commonly known as IPTV. Typically, these services require a fairly high-bit-rate DSL service that is very stable and error-free. As service providers migrate from "best effort" delivery of Internet and e-mail services to the triple-play delivery of HDTV television, VoIP and Internet services, the demand for circuit-by-circuit testing becomes more critical.

Today, there are a number of different DSL technologies available, each offering different speeds for different needs and applications. Regardless of the technology, DSL offers fast speeds for both the residential and the business customers. Various types of DSLs have been designed to either operate over one or two pair(s) of copper cable. For example, HDSL was originally designed as a two-pair technology, while ADSL was conceived as a single-pair technology from the start. ADSL was created to coexist on the same pair of copper cable as analog voice transmission (i.e., POTS), allowing users to use their existing phone lines.

In addition, ADSL can also coexist on the same cable pair as basic-rate ISDN transmission so that users do not have to give up the dedicated digital voice, fax, data, and video link they already enjoy in order to subscribe to high-speed access to the Internet. Although ISDN is not commonly distributed to

residential customers in the Bulgaria (city Gabrovo), it is quite important in many European countries and elsewhere in the world.

All the various DSL technologies are provisioned via pairs of DSL modem-chip sets, with one modem-chip set located inside the DSLAM either in the CO or in the remote cabinet, and the other at the customer premises inside the DSL modem/router. Although rarely labeled DSL, integrated-services digital network (ISDN) service is a unique example of type of DSL because although it is a digital technology, it uses analog signals over the existing telephony local-loop cabling infrastructure. However, ISDN differs from pure DSL technologies in that it is a public switched-network service, as apposed to DSL that is point-to-point over the local loop and generally ATM- and/or IP-concentric.

Some of the more popular xDSL technologies are described as follows:

– Integrated-services digital network (ISDN) – can be considered one of the first DSL technologies. ISDN was developed to simultaneously carry digital voice, data, and images over conventional copper cable. Basic-rate ISDN is comprised of three logical channels operating over a single copper pair. Two bearer channels (B channels) carry the voice, data, and images, while the one signaling/control channel (D channel) is used for signaling. ISDN offers speeds of up to 160 kbps symmetrically. ISDN is also available in a primary-rate interface (PRI) configuration. The PRI offers data/voice/image transfers of up to 1,544 Mbps (North American T1 format) over 23 B channels with one D channel or up to 2,048 Mbps (European and international E1 format) over 30 B channels with one D channel. Each channel in the PRI configuration operates at 64 kbps.

ISDN uses a 2B1Q line coding (two binary, one quaternary) to represent information. 2B1Q maps two bits of data into one quaternary symbol, i.e., onto four voltage levels that represent two bits of digital information at a regular clocking rate.

– ISDN digital subscriber line (IDSL) – is similar to ISDN except a packet router replaces the CLASS 5-style switch at the central office. With this technology, there is generally only one logical channel containing all the information. IDSL is always connected to the server and therefore “calls” do not to be set up. This type of service is now considered obsolete technology that has mostly been replaced by ADSL, ADSL2+ or SHDSL.

– High-bit-rate digital subscriber line (HDSL) – is a symmetric DSL similar to T1 or E1 in that it delivers a bit rate of up to 1,544 or 2,048 Mbps. Most HDSL systems use one or two copper cables, twisted pairs, although some very early 2,048 Mbps systems required three copper twisted-pair cables. HDSL is comprised of an HDSL transceiver unit, located at the central office (HTU-CO), and a remote HDSL transceiver unit (HTU-R), located at the customer premises. HDSL’s operating range, in terms of distance, is more limited than that of SHDSL, ADSL and ADSL2+. Normally, an HDSL service can only serve customers within 3,6 km of the serving office. Beyond such distances, signal repeaters are needed to extend the service.

As HDSL requires two twisted pairs, it is deployed primary for businesses that require private branch exchange (PBX) network connections, virtual private networks (VPNs), frame-relay circuits, Internet access, and private data networks. HDSL uses 2B1Q or carrier-less amplitude/phase modulation (CAP)-based line coding.

HDSL2 and SDSL are similar technologies to HDSL in operation, but they are capable of achieving HDSL rates over a single pair of wires. This tends to limit transmission distances, but it is still a successful technology.

Symmetrical high-speed digital subscriber line (SDHL) – is a technology that is similar to HDSL and

ISSN 1313-2539, Published at: http://www.science-journals.eu

HDSL2. SDHL operates over a single pair or two pairs of wire, depending upon the application. For single-pair operation, SDHL offers data rates from 192 kbps to 2,3 Mbps in a symmetrical fashion, while two-pair operation offers data rates ranging from 384 kbps to 4,72 Mbps.

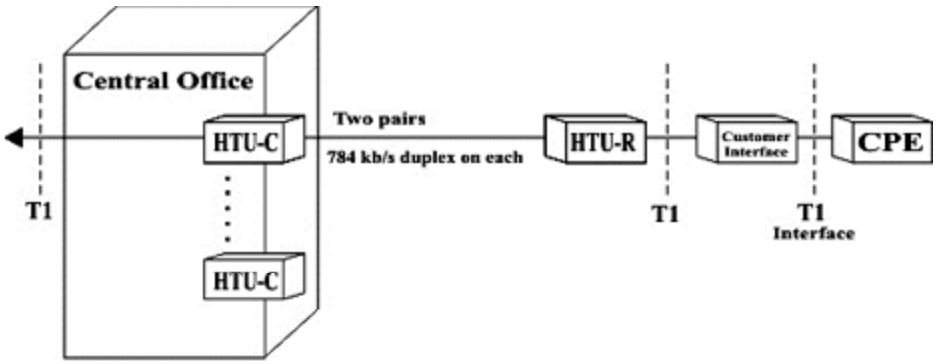


Fig. 2. HDSL architecture.

SDHL is designed to be more of a business solution than a residential service due to its symmetry. It can be used as a T1/E1 replacement technology and is also well-suited for VoDSL solution.

SDHL has been developed to be spectrally compatible with other technologies within bundles of local loops. SDHL owes this to the trellis-coded pulse amplitude modulation (TC-PAM) line coding. This coding technique maximizes the use of the lower frequencies of available loop bandwidth, thus avoiding higher frequencies where signals are more susceptible to crosstalk.

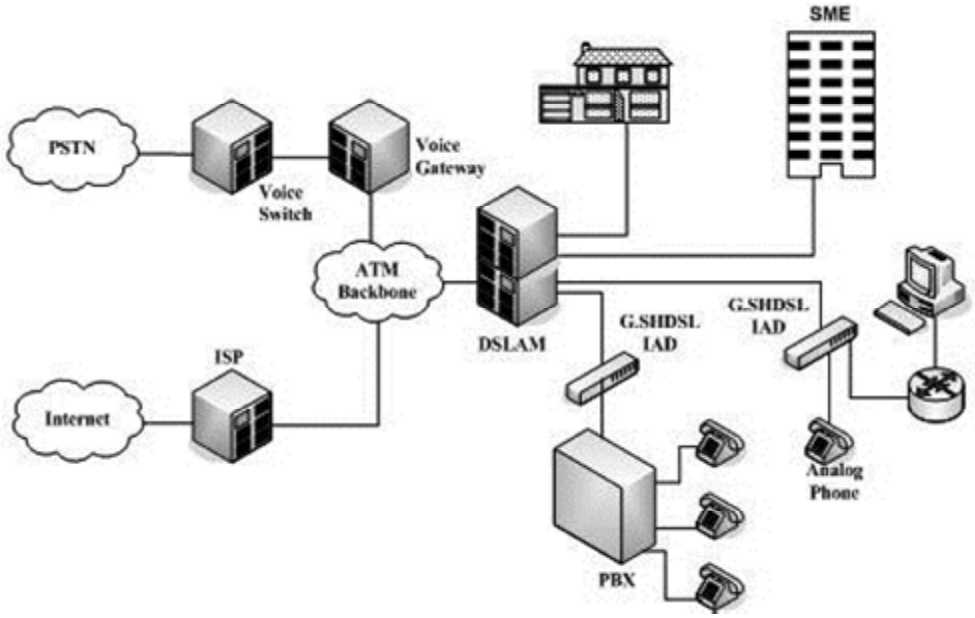


Fig. 3. SDHL architecture.

ISSN 1313-2539, Published at: http://www.science-journals.eu

– Asymmetric digital subscriber line (ADSL) – provides delivery of high-bit rate digital technology for consumer-based Internet access. ADSL delivers more bandwidth downstream (from the service provider to the subscriber's premises) than upstream (from the subscriber premises towards the network). As most users view far more information than they create, ADSL is optimal for Internet and other IP-based services. Downstream rates range from 256 kbps to 9 Mbps, while upstream bandwidth ranges from 16 kbps to 640 kbps. ADSL transmissions may work at distances of more than 5,4 km over a single copper twisted pair of wires, although it should be noted that only the lowest bit rates are available at these lengths.

–

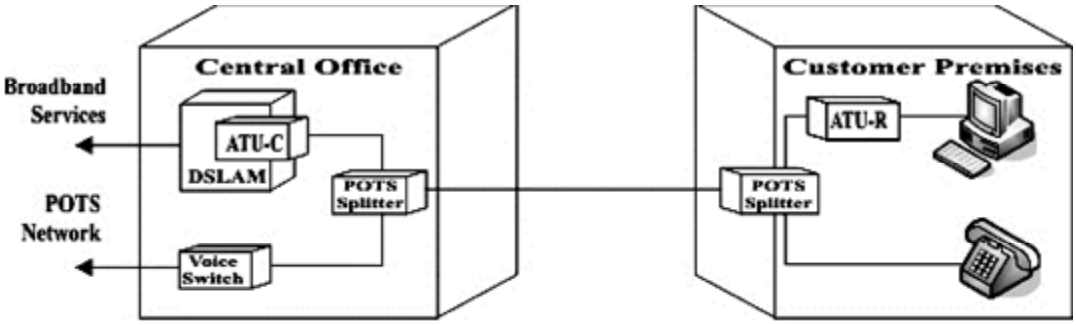


Fig. 4. ADSL architecture.

For service providers and customers alike, ADSL allows subscribers to simultaneously use their existing phone line for high-speed Internet access as well as regular (including vital life-line) plain old telephone service (POTS). ADSL signals are able to coexist on the same loop as POTS service because they occupy a higher frequency band than POTS. Typically, ADSL uses the 25 kHz to 1,104 MHz range, while POTS uses the 300 Hz to 3400 Hz range. As a necessary precaution, a low-pass filter is placed on the line to separate ADSL signals from POTS signals. These small devices allow voice band frequencies to pass through to analog telephones while keeping the high-frequency signals of ADSL away from the phones. Likewise, the input filters in ADSL modems prevent telephone signals from entering. In a similar fashion to ADSL and POTS on the same line, ADSL can also coexist with ISDN. Since ISDN operates in the bandwidth up to 150 kHz there are fewer ADSL subchannels that can be used for ADSL data transmission resulting in a lower achievable data rate. ADSL modems that are designed for use in conjunction with POTS services only are referred to as Annex A modems, whereas those designed to work on loop with ISDN are called Annex B. Both of these designations come from the annexes of ANSI T1E1.4 published standards.

Two types of line coding exist for ADSL. An early scheme used a non-standards-compliant carrier-less amplitude/phase modulation (CAP) method. This modulation technique is very similar to that used for dial-up modems. These days, virtually all ADSL DSLAM and modems use the discrete multitone (DMT) technique.

A DMT transmission scheme divides the frequency band from 0 Hz to 1.104 MHz into equally spaced subchannels or "bins". This equates to a total of 256 bins. Each bin occupies 4,3125 kHz of bandwidth.

In systems that use echo cancellation – a method where the upstream and downstream tones coexist at the same frequencies – 32 bins are allocated for upstream transmission, and up to 250 bins are allocated for downstream transmission. For the most part, however, DMT implementations will use 218 bins for downstream signals. Guard bands that separate the upstream signals from the downstream

ISSN 1313-2539, Published at: http://www.science-journals.eu

signals use some of the possible carrier allocations. There is also a guard band between the POST signals and the DMT carriers of ADSL signals.

DMT standards suggest that equipment can use up to 15 analog levels per frequency bin to encode data per subchannel. However, using the maximum 15 states per bin may result in the overall ADSL transmit power to be higher than would be practical or allowed by government regulators in a cable bundle. For the most part, ADSL makes have limited their designs to use 13 or 14 bits/bin. This lowers the power transmitted between modems and maximizes the reach of transmission without compromising potential data rates.

– Rate-adaptive digital line (R-ADSL) – This was an early name for specific type of ADSL modem that adjusted the transmission speed dynamically to the length and quality of the local loop. These days, most ADSL modems are rate-adaptive and most DSLAM network management systems allow the transmission speed to be set or limited to a maximum bit rate.

– G.Lite – This is a lighter version of a ADSL in which downstream rates are limited to approximately 1,5 Mbps. G.Lite uses 128 bins rather than 256 (still using 4,3125 kHz subchannel bandwidth) and only up to 8 states/bin can be encoded per subchannel.

– ADSL2 – This is an improved version of ADSL with slightly better data rates. Described in ITU-T standards G.992.3 and G.992, ADSL2 can offer the same bit rate over longer loops and also includes on-the-fly rate adaptation as well as certain diagnostics of the local loop. ADSL2 modems should generally be backward-compatible with ADSL modems.

– ADSL2+ - Shortly after the release of ADSL2, the standards for ADSL2+ (ITU-T standard G.992.5) were published, and chip sets than supported the technology became available. This scheme more than doubles the downstream data rate of ADSL to 25 Mbps by doubling the utilized bandwidth (from 1,1 MHz to 2,2 MHz) and doubling the number of DMT carriers (from approximately 256 to approximately 512).This access technology is primarily designed to enable the delivery of streaming broadcast-quality video to subscribers. ADSL2+ modems also offer the full capabilities and interoperability of ADSL and ADSL2 modems.

– Reach-extended ADSL2 (RE-ADSL2) – This variety of ADSL was approved by the ITU-T in October 2003 and is described in Annex L of the document. The RE-ADSL2 transmission scheme carries fit to newly defined power spectral-density masks that reduce the crosstalk interference from pair to pair, thus increasing the ADSL2 reach.

– -Very-high-speed digital subscriber line (VDSL) – The intent of VDSL is to provide users with very-high-speed asymmetrical and symmetrical services by placing carries at frequencies of up to 12 MHz and supporting bit rates as high as 52 Mbps. The trade-off of VDSL is that it can only operate at higher bit rates on relatively short loops (less than 1350 m). To achieve the short distances and high rates, VDSL is typically deployed in a fiber-to-the-curb (FTTC) architecture, in which a fiber-optic backbone (OC-3, OC-12, OC-48, GigE, or 10GigE) network feeds a neighborhood. Because of the loop's distance limitations and the cost of deploying fiber-optic cable to each serving area, VDSL has been mostly successful in multitenant units (MTU) or multidwelling units (MDU) although some carries have announced plans to deploy large-scale VDSL2.

ISSN 1313-2539, Published at: http://www.science-journals.eu

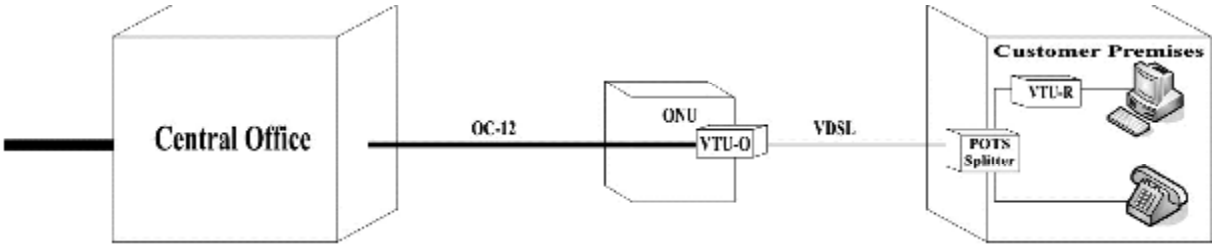


Fig. 5. VDSL architecture.

The standards bodies such as ITU-T and ANSI Committee T1 have preliminarily defined VDSL to use frequencies up to 12 MHz. Maximum asymmetrical data rates of 22 Mbps (downstream) and 3 Mbps (upstream), and maximum symmetrical data rates of 13 Mbps.

Table 1. Data rates for asymmetrical and symmetrical service.

Service Type	*Downstream Data Rate (Mbps)*	*Upstream Data Rate (Mbps)*
Asymmetrical	22	3
Symmetrical	6 13	6 13

The typical makeup of a VDSL deployment will consist of an optical network unit (ONU), a VDSL transceiver unit ONU (VTU-O), and a remote VDSL transceiver unit (VTU-R).

VDSL can operate in two modes depending upon the manufacturer and service provider. The VDSL standard proposes two line-coding techniques – single-carrier modulation (CAP), and multicarrier modulation (DMT).

– Very-high-speed digital subscriber line, version 2 (VDSL2) – This standard (G.993.2) was approved by the ITU in May 2006. Like ADSL and ADSL2+, VDSL2 is based on DMT modulation code. It provides spectral compatibility with existing services and enables backward interoperability with ADSL.

VDSL2 is a true worldwide standard, providing numerous configuration profiles and band plans to meet regional service-provider requirements. Its frequency bandwidth has increased to 30 MHz, with configuration options at 8,5 MHz, 12 MHz, 17,7 MHz and 30 MHz. With VDSL2, the potential for data rates over 100 Mbps is possible on very short loops (less than 300 m), which makes it ideal for deployment in FTTN and FTTB networks.

The latter offers several capabilities to benefit service providers. Among them are the following:

– Extended reach – VDSL2 takes advantage of the first upstream band (US0), which consists of the same upstream frequencies used by ADSL2+. The use if US0 requires training sequences similar to those used for ADSL to train equalizers and echo cancellers.

– Impulse noise protection – Electrical appliances often generate short burst high-amplitude noise called impulse noise. Impulse noise could cause large burst of errors, which could have a significant impact on video services. VDSL2 takes advantage of its inherent impulse noise protection (INP) capability to correct the errors as they happen.

ISSN 1313-2539, Published at: http://www.science-journals.eu

– Improved quality of service with dual latency – Dual-latency operation mode for VDSL2 has been adopted to better support triple-play applications. As video services must be immune to short burst of errors, they have generated a need for error-protection such as greater interleaves depth. Although this will cause them to experience more latency, video services are not sensitive to delay assuming that they are in a specified range and that there is little jitter present. Voice, on the other hand, does not require excessive error protection but is very sensitive to delay. Being able to configure dual latency is therefore a considerable advantage for delivering triple-play services.

– Packet transfer mode – In recent years, we experienced the transition from ATM to IP for backbone networks.VDSL2 allows the industry to drop ATM in the first mile and replace it with Ethernet. IEEE 802.3ah has defined a specific Ethernet TPS-TC using the 64/65-octet encapsulation for Ethernet applications without an underlying ATM. In the ITU-T VDSL2 specification, TPS-TC is referred to as PTM-TC.

–

4. DSL TESTING AND LOOP QUALIFICATION

With the growth in Internet, video on demand (VoD), broadcast/multicast video services (IPTV) and small office/home office (SOHO) applications has come an increased emphasis on providing stable, high-speed, broadband connections. One way to guarantee stability and to ensure maximum bit rates is through an increased level of service and local loop testing. Most providers have adopted, or are turning to, pre-qualification of copper loops in order to determine if local loops are capable of supporting various DSL transmission rates. Defining a superior installation and maintenance plan is becoming critical in terms of service provider competitiveness. The more than is known about the local loop, the greater the efficiency of repair crews and the lower the risk of customer disappointment through installation delays, intermittent failures, or under-performing service.

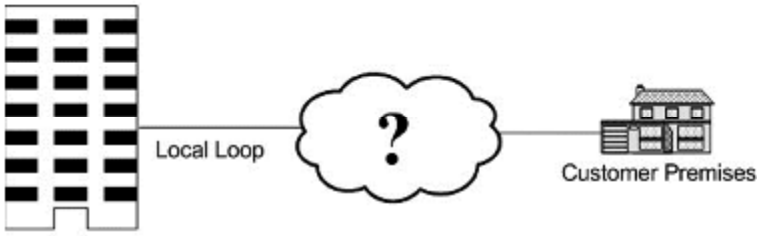


Fig. 6. Testing the local loop answers many questions.

Frequency Response. It is very intuitive that the longer a twisted-copper telephone cable is, the greater the DC resistance. Like any conductors that are wound in spiral fashion (i.e., twisted pair), telephone cable also has a certain amount of inductance per unit length. When all of these factors (L, R, C) are taken into account, it can be seen that twisted-pair cable has complex impedance that varies with length.

Twisted-pair cable therefore has a non-linear attenuation. Higher frequencies are attenuated more than lower frequencies, and this effect is enhanced on longer circuits. The end result is that short cables have less attenuation overall, and the difference in attenuation between low frequencies and high frequencies is not as pronounced. On the whole, long cables have greater attenuation as compared to short cables. In addition, the higher frequencies on long cables are more greatly attenuated when compared to lower frequencies.

Measuring the frequency response of a local loop involves inserting a test tone of a known power level at one end and measuring the power of the tone after it passes through the loop. The difference in power level between the transmitted test tone and received test tone is the attenuation at that frequency. By stepping through a number of different frequencies, the frequency response of the circuit can be determined. Telephone company personnel may also refer to this as insertion loss, attenuation, level tracing or slope. It is also possible to measure the insertion loss of a local loop from just one end of the local loop. This is achieved by creating an open circuit or short circuit at the far end of the loop. After some isolation, the transmit signal is canceled from the receive signals. That leaves only signals that have traveled the length of the circuit, that have been reflected back from the open or shorted end of the cable and once again traveled the length of the local loop. The one-way attenuation is one half of the overall attenuation measured.

With the results from this test, a technician can determine if various points of loss across the specific bandwidth of interest are too great to be able to transport DSL signals.

Insertion Loss at a Specific Frequency. A single frequency measurement of insertion loss is not effective for testing loops for their ability to carry the DMT signals of ADSL transmission. A single bridged tap can cause a reflection that effectively nulls the test tone at the test frequency. A bridged tap will only knock out very few frequencies. Therefore, it is possible to have a huge attenuation at a chosen test tone frequency but, in reality, have an excellent transmission path for ADSL. On the other hand, technologies like HDSL, HDSL2, ISDN, IDSL, and SHDSL use a signature frequency that can be tested using a single test tone. Inserting a tone at these specific frequencies can be used as a rough method to determine the stability of the loop. This is a good way to approximate the response of the actual system. If the loss at the "signature" frequency is out of pre-set limits, technicians can isolate loop problems before attempting to install the transmission hardware. The adjacent table lists the signature frequencies commonly used to test each technology. Notice that IDSL and ISDN use the same test frequency. HDSL2 and SDSL also use the same frequency.

Table 2. Frequency used various DSL services.

Technology	***Signature Frequency***
ISDN/IDSL	40 kHz
HDSL	196 kHz
HDSL2/SDSL	392 kHz

Noise and Crosstalk. Noise is any unwanted signal that could adversely affect the desired signal as it passes through the transmission path. The end result might be a corrupt signal that can be misinterpreted by the receiver. This is translates to errors in the digital bit stream.

The noise found on local loops is caused by many sources: light dimmers, radio signals, neon lights, electrical trains, and adjacent power lines are a few examples. The most common and problematic types of noise are caused by the electromagnetic coupling of signals from one local loop to another within the same cable bundle. This effect is known as crosstalk. In fact, the reason that telephone cable is twisted is to reduce crosstalk.

A quiet terminated noise measurement is the best method for measuring noise. Again, it is desirable for the technician to be able to view a spectral display (spectrum analysis) of the measured noise. Because ADSL, ADSL2+ and VDSL2 use many carriers (up to 4096 subchannels), so long as the

ISSN 1313-2539, Published at: http://www.science-journals.eu

total power of the noise is concentrated in narrow band of frequencies, DSL transmission is still possible. For this reason, a numeric measurement of the total noise power in the transmission bandwidth is absolutely meaningless. Only a measurement that shows the noise distribution in each carrier's bandwidth has any meaning. The telecom industry has coined the term power spectral density (PSD) to indicate the graphical display of noise power at various frequencies.

The effect of crosstalk can only be determined in "live" bundles that already carry several DSL services. Consider, for example, an F2 facility with a pair count of 25. If no DSL or other higher-rate services have been deployed on that bundle, there is no useful crosstalk information to be measured. Once the first DSL circuit is deployed, the amount of crosstalk in the band of interest will drastically increase. Each subsequently added DSL service will continue to add to the crosstalk level.

Impulse Noise. Spikes of transient voltages or noise can also disturb a modem's ability to discern between coding levels or states. If these impulses happen often enough, they can take bandwidth away from the transmission path. Therefore, the common signal coding that carry DSL (DMT, CAP, 2B1Q and TC-PAM) signals can be equally affected. For this reason, measurements of impulse noise are important.

In order to measure only the impulses that affect the DSL of interest, the American National Standards Institute (ANSI), the European Telecommunications Standards Institute (ETSI) and the International Telecommunications Union, Telecom (ITU-T), all which are standards bodies, have defined various noise filters. The table below lists those filters, along with their bandwidths and their application:

Table 3. Filters defined by standards bodies.

Filter	***Related Technology***	***Frequency Band***
D Filter	DDS	0 kHz to 32 kHz
E Filter	ISDN	1,0 kHz to 50 kHz
F Filter	HDSL	4,9 kHz to 292 kHz
G Filter	ADSL	20 kHz to 1,1 MHz

Longitudinal Balance. A proper pair of local-loop wires consists of two conductors, both of which are floating and balanced with respect to ground. Measuring the longitudinal balance of a pair gives an indication of the differential voltages caused by imperfect balancing of tip and ring with respect ground. The measurement is given as a level in dB. The higher the dB reading, the better the balance of the cable pair under test. A poorly balanced pair invites greater near-end crosstalk (NEXT) or far-end crosstalk (FEXT) that may disturb the carried signals.

Longitudinal balance is affected by short circuits, or partial short circuits, between either conductor and the cable sheaths and other ground sources. Water in the cable is one of the principal sources of partial conductivity to ground.

For DSL deployments and loop fault-finding, it is important to measure longitudinal balance at many frequencies across the utilized bandwidth. Although a DC fault (i.e., conductivity to ground) will cause problems with longitudinal balance across all frequencies, AC faults (i.e., capacitive conductivity to ground) may only present itself as high-frequency imbalances. Capacitive faults occur when cable bundles are squeezed or kinked during installation or with frost heaving, earthquakes, construction loading, etc.

Load-Coil Detection. Load coils were introduced in the local loop to lessen the effect of non-linear attenuation on voice circuits, usually on lines exceeding 18 kft. These series of inductors cause a flattening of the frequency response in the voice band that allows long-length loops to carry acceptable voice transmission.

Load coils result in large attenuations of signals at higher frequencies, making the transport of DSL signals impossible. As a result, it is necessary to find and remove all load coils on a circuit intended for such services.

A TDR may be used for a graphical interpretation of faults on a line and their respective location. In ideal conditions, a load coil procedures a spike in the TDR plot. This is an effective test, but it leaves the user to determine which spike is, in fact, a load coil and which is another type of cable fault.

A load coil can also be found by using impedance vs. frequency plot. This test is performed using one test set from one of the cable. A loop that does not have load coil will have a smooth, ascending impedance plot, whereas a loop with load coils will have swings in impedance.

Bridged Taps – are unterminated lengths of wire connected at some point along the utilized local loop. Various names exist for bridged taps, including laterals, multiple appearances, tail circuits, etc. As a common practice, most bridged taps were installed as a planning measure so that plenty of local loops would be available for subscribers without doubling the capacity of feeder cable (F1) bundles. Bridged taps cause a reflection of the original signals that are delayed in time and somewhat attenuated. These signals can confuse DSL receivers and cause bit errors which can result in poor DSL service. A degradation of 300 kbps or more could be experienced.

Other sources of bridged taps include subscribers, contractors or poorly trained technicians who perform wire repair or circuit rerouting. Technicians often leave an unused section of wire pair connected to the newly installed pair, thus producing an unwanted bridged tap.

Many negative effects caused by bridged taps can be reduced or eliminated by the digital signal processing algorithms found in most DSL systems [7]. The taps that create the most problems would be those that are located near the CO or the remote terminal. In practical terms, this generally means the taps within the customer premises or multiple appearances in the local distribution cable (F2). These taps need to be found and removed.

One special case to note is when the lateral (bridged tap) is longer than the primary path to the subscriber. Automatic CO-based loop-qualification test systems that use reflectometry technology to determine the end of a cable will be fooled into thinking that the end of the lateral is the end of the cable and that the end of the bridged tap is the end of the loop. Frequency-domain reflectometry (FDR) is the best method to locate bridged taps.

Split Pairs. The pairs of wires within cable bundles are twisted for a number of reasons, namely, to reduce the amount of crosstalk coupled to/from adjacent pairs. Telephone-company personnel utilize pairs as needed for customer services. In neighborhoods or business parks, where spare pairs have become scarce, telephone technician have often turned to “split” pairs to deliver service. A split pair is created from two semi-defective loops, each of which contains a single broken conductor. By using the remaining good conductor from each pair, an additional pair is gained.

Identifying split pairs within cable bundles that already have other DSL circuits within the same binder group is quite simple. Since a split pair does not have a consistent twisting between its two conductors, it will pick up more crosstalk than normal pairs.

High-Resistance Faults. The copper-loop plant is generally a blend between old and new facilities. A typical loop plant is made up several different types of cable of various gauges. Typically, 19, 22, 24

and 26 gauge cable is used in the USA and Canada with 0,4, 0,5, 0,6 and 0,8 being used in Europe and the rest of the world.

Some cable bundles are pressurized with compressed air. The positive pressure prevents water from entering should the cable be damaged.

When cable is produced at the factory, the process can create pinholes in the insulation. The aging process, lightning strikes, and other factors can create faults.

With plastic-insulated cable (PIC) and especially jelly-filled PIC, faults develop slowly over time. Typically, the insulation around a single conductor will be nicked. The differential voltage between the conductor (tip or ring) and the cable bundle's shield will cause the ions in the water to bond to the conductor as electrolysis takes place.

Faulty Splices. Local-loop facilities are rarely straight runs of manufactured cable bundles. Typically, a local loop is comprised of several sections that have been spliced together. Over time, splices tend to oxidize (corrode), become damaged through electrolysis or suffer physical separation.

Usually, a splice becomes a partially open circuit before it becomes a fully open circuit. Any break or degradation in the path of the two conductors of a pair will cause DSL circuits to fail. Finding a bad splice is easily done using a TDR or FDR technique.

Resistance Fault Location. To locate high-resistance faults, a resistance fault location (RFL) test should be performed. The first task is to determine if the fault is between tip and ground, ring and ground, or tip and ring. A good test unit will determine this by automatically measuring the resistance between all three conductors. Once the fault is identified, the tester automatically instructs the technician to create certain "straps" at the other end of the loop. Normally, a technician will isolate one section of cable bundle that contains the fault before the final locate is performed.

It should be noted that an RFL measurement consists of determining resistance. Distances are calculated by the measuring instrument through resistance to distance calculation.

5. RESULTS

The measurements are conducted for an intra-city subscriber line including a central office (BTC) and the Technical University of Gabrovo, Building 2, having a line of 3 km. The measurements have been taken using an ADSL modem ZTE ZX DSL 831 and Subscriber Line Testers SLT-22 [4], by means of which the results are presented in both tabular and protocol form (Figure 7 and Table 4). Table 5 shows the results of a measurement of an HDSL line using HP37732A [5].

ISSN 1313-2539, Published at: http://www.science-journals.eu

Table 4. Results of the measurement of an ADSL subscriber line using Subscriber Line Tester SLT-22.

Att		+ 23.7 dB
S/N	***N***	+ 49.9 dB
	F	+ 44.3 dB
DC - R		627 Ω
I - Noise	***N***	8 mVp
	F	2 mVp
W - Noise	***N***	- 65 dB/m
	F	60 dB/m
User Def	***Up***	857 kbps
	Down	5369 kbps

Table 5. Results of the measurement of an HDSL subscriber line using HP37732A.

Bit Error Results	***Error count***	0
	Average Error Ratio	9,9.E-01
Block Results	***Block Count***	0
	Block Error Ratio	0
	Block Error Count	0
Clock Results	***Clock Slips***	N/A
Bit Analysis	***%Availability***	100,00%
	SES	2
	ES	2
	DM	0
	LTIMER	0
	Unavailable Seconds	0
	%SES	100,00%
	%ES	100,00%
	%DM	0,00%
Alarm Seconds	***Power Loss***	0
	Pattern Loss Seconds	2
	Clock Slips Secs	0
	Error Seconds	0
	EFS	0,00%
	Data Loss	2
	Pattern Loss Events	0

ISSN 1313-2539, Published at: http://www.science-journals.eu

```
HEWLETT-PACKARD HP37732A                                  Serial No. 3606U03347
-------------------------------------------------------------------------------

CURRENT SETTINGS SUMMARY:
Application       : DATACOM              Interface        : X.21 LEASED
Emulate           : DTE                  Timing           : SYNCHRONOUS
Tx Clock Source   : INTERFACE            Clock Edge       : RISING
Rx Clock Source   : INTERFACE            Clock Edge       : FALLING
Pattern           : 2^15-1     NORMAL    Block Length     : AUTO
Tx Data Polarity  : NORMAL               Rx Data Polarity : NORMAL
Rx Sync Loss      : AUTO                 Threshold        : LOW

Tue, Apr 04, 2006 09:14:22  RESULTS AT END OF LAST TEST PERIOD
Elapsed Time  00d 00h 02m 02s

CURRENT RESULTS SUMMARY:
Bit Error Results
   Error Count..................... 0   Error Seconds..................... 0
   Average Error Ratio............. 0   EFS.................. 122    100.00%
Block Results
   Block Count.................... 7682  Block Error Count................. 0
   Block Error Ratio............... 0
Clock Results
   Clock Slips..................... 0
Bit Analysis
   %Availability.............. 100.00%  Unavailable Seconds.............. 0
   SES............................. 0   %SES........................... 0.00%
   ES.............................. 0   %ES............................ 0.00%
   DM.............................. 0   %DM............................ 0.00%
   LTMER........................... 0
Tx & Rx Rates
   Transmit Frequency........2047972 Hz  Receive Frequency........2047972 Hz
Alarm Seconds
   Power Loss...................... 0   Data Loss........................ 0
   Pattern Loss Seconds............ 0   Pattern Loss Events.............. 0
   Clock Slip Seconds.............. 0
```

Fig. 7. Protocol of the testing of a digital line at TF = 204772 Hz.

6. CONCLUSION

An actual subscriber line of length 3 km has been used and the errors have been measured in order to assess the quality of digital information transfer by means of local-loop and xDSL.

The errors identified with the BER test are due to a poor-quality junction box on the respective floor. The User Def measurements shown in Table 4 are satisfactory. The measurement has been conducted using two devices, one at the close end and another one at the distant end. Out of the pair measured for an xDSL service, a reserve of 2.5 times of the values shown is needed for normal operation – User Def (Table 4). It has been proved in practice that when 30 % of digital service deployment has been reached for the channel, the distance at which this service can be provided becomes shorter.

Based on what has been discussed thus far, below is a summary of what can be done to perfect local-loop testing techniques.

1. Use a butt set to determine if there is a signal present on the line (voice or other to determine if circuit is free).

2. Use the PSD analyzer to determine if any of the circuit has live DSL, T1 or 2 Mbps (E1). The PSD analyzer should be able to indicate the underlying technology.

3. Do not continue to test or interrupt service if the circuit is live based on points 1 and 2 (i.e. greater than -40dBm RMS of signal).

ISSN 1313-2539, Published at: http://www.science-journals.eu

4. If this is dry pair or if the customer has acknowledged that service will be interrupted, move on the next cable.

The weakest link in the DSL chain is the local loop. Each one is slightly different from the next. They vary in length, quality, and noise levels. When DSL services don't work, or connect rates to be improved, it is time to bring out proper cable troubleshooting tools.

REFERENCES

1. Knightston, K., Basic MGN Architecture & Principles, Canada, 2004.

2. Fitts, R., Ch. Dunford, F. Hodis, Local-loop and DSL. Testing Reference Guide, Second Edition, EXFO, 2007.

3. Penchev P., K. Monov, Assessment of an intra-city subscriber line for digital data transfer, Electronics'2006 National Conference with international participation, 1-2 June, Sofia (in Bulgarian)

4. ITU-T G.821, "Error performance of an international digital connection operating at a bit rate below the primary rate and forming part of an integrated services digital network".

5. Operating Manual, SLT-11/SLT-22 Subscriber Line Tester, WG, BN 2257/98.11.

6. Operating and Calibration Manual, HP 37732A, Hewlett-Packard Ltd. 1991.

7. Karapenev B., Levelling of energy signal and displacement of domestics – one of the main processes in the channel coding, Journal of the Technical University of Gabrovo, volume 41' 2011.