University of Piraeus

ΠΑΝΕΠΙΣΤΗΜΙΟ
ΠΕΙΡΑΙΩΣ

Cognitive Copper Management

MSC thesis

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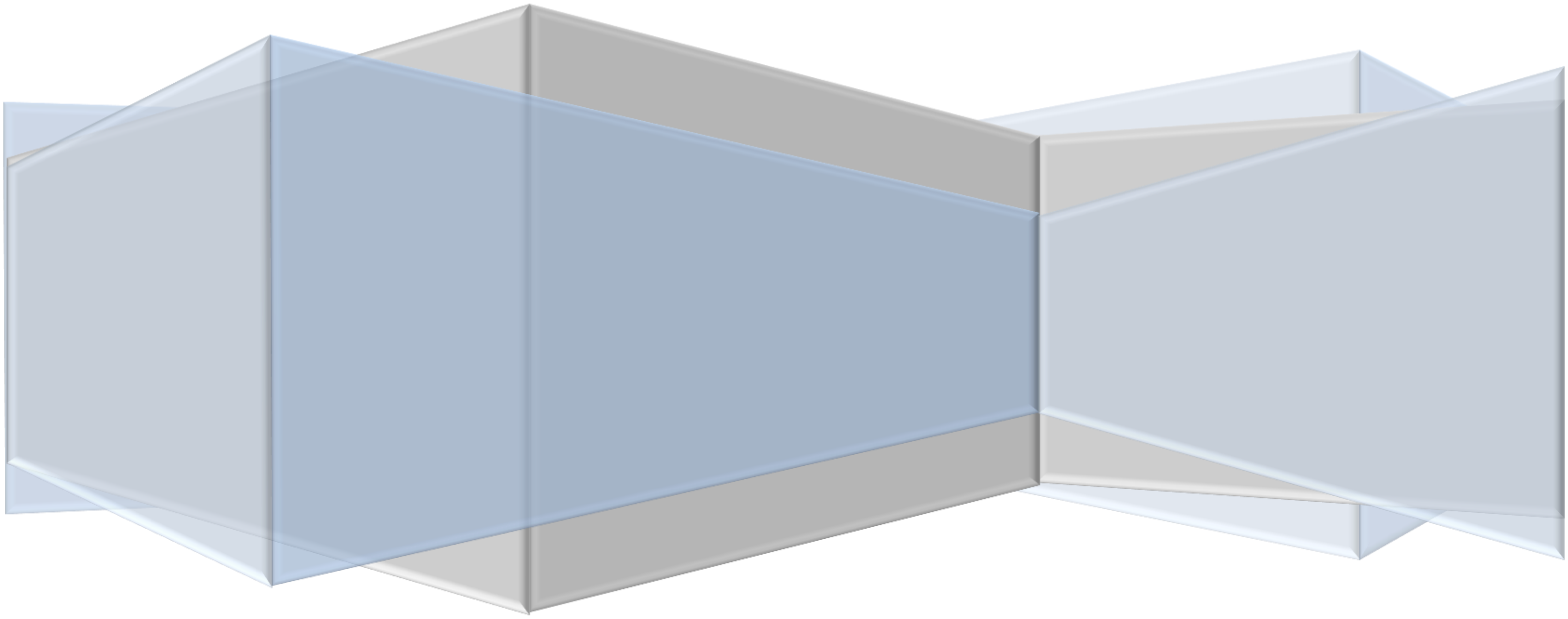

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Abstract

The current world financial crisis has been extended to all sections of economy. Telecommunications is a sector that has been much affected and the outcome of this has slowly started to grow: consolidations as the only way of surviving, bankrupts of ICT companies, loose of faith of investors etc. This uncertain and risky environment, demands a closer look on the investment plans of telecommunication companies, minimization of the OPEX and capitalization of the used CAPEX. On the other hand, plans for new services like high definition channels of IPTV and other bandwidth demanding applications, in most of European countries, seem that have not the penetration operators have visualized. As a result, FTTH -FTTC (fiber to the home – cabinet) networks that realize such services but require vast amounts of investments in civil works, are kept aside as potential future plans. Fixed operators are trying to find ways to fully utilize their existing investments, selling access and content to subscribers using the old copper infrastructure as the physical medium for these services.

The old copper infrastructure initially does not seem as an appropriate medium for such services. There are drawbacks of using it to serve the subscribers and there always is a question to proceed to new investments of fiber. The problems of the medium come from the fact that this infrastructure was built around the second half of the previous century and its purpose was to deliver analogue voice service. No proper shielding, frequent oxidations, wet sections, bridge taps, unbalanced loops, impulse noise and crosstalk problems, are all problematic situations describing the copper condition. In many countries, copper infrastructure is usually controlled by the (former) public operators providing unbundled access to others, the so called local loop unbundling - LLU.

Though technology has evolved and telecommunication manufacturers could provide more sophisticated equipment. Telephony became digital and data services arrived. ADSL2+ is a technology providing line rates of up to 24Mbps in downstream direction and 1mbps in the upstream. Packets transferred using the copper, made the medium adequate for not real time application, such as internet browsing. The big problem came when real time, high bandwidth applications were needed to be served. For example, 2 high definition channels of IPTV in mpeg4 coding require around 9mbps of synchronization rate, in an error free line. The attempt of selling this service, apart from the factor that the coverage is limited, requires a huge amount of OPEX for truck rolls with field engineers in order to guarantee the quality of the copper and back office engineers for monitoring lines, providing relevant settings to the network equipment for the lines' unique settings.

As mentioned also in the beginning of this chapter, minimizing OPEX is the target for operators, maintaining at the same time high quality in the given service. The way to achieve such a goal can only be realized with the use of innovative technologies in their operation lifecycle. Advantages like these can be offered by a cognitive administration or control of the copper network. In other words, informational systems that are collecting statistics, providing fault localization, measuring with KPIs (key performance indicators) the given quality of service, predicting the possible offered quality on a local loop, while at the same time taking autonomous decisions for reconfiguration management about service initiation, spectrum coding and rate settings.

In the beginning of this thesis, an attempt to describe the key points of copper network and the services offered over that will be done. Design aspects of a cognitive system specialized in copper networks will follow, clarifying the puzzle of the components that are used to be integrated in order to provide the, as already described, desired result. Last, the outcome of the adoption of such a system in a European operator is presented.

Part I: xDSL networks and management systems

Fixed broadband networks

The LLU and sub-LLU infrastructure

The copper infrastructure was built around the second half of the previous century. In that network topology multiplexing of lines was performed in local exchanges, or central offices (LE or CO),where the telecommunication equipment was located. From there, a copper pair started, ending up to a conjunction box (KV) in a neighborhood area. This infrastructure was fixed and for every subscriber, a copper pair started from the conjunction box, entering into an intermediate box inside the building and ending up to the subscriber's apartment. The loop length (from the local exchange up to the subscriber) could be a few kilometers in the beginning, though with techniques that took advantage of load coils the loop length could multiply.

Not many things have changed in today's LLU topology. Actually almost nothing has changed as far as the copper pairs topology, except the fact that the load coils are no longer used. Several new local exchanges have been created, shortening the copper length usually up to 5 Km, since ADSL2+ (Asymmetric Digital Subscriber Line) technology offers high speed internet access to a loo length up to 6 km. Though, differences appear in the local exchange. There, a main distribution frame is located where the copper infrastructure is connected and numbered. Each pair that ends up to a subscriber is connected to a filter/splitter. The role of this is to combine/split the services of telephony and xDSL. A pair starts from the splitter and is connected to the device that generates the xDSL signal (DSLAM), while a second one is connected to the device that generates the telephony service (telephony access gateway). On the subscriber side, the difference is inside the apartment. A second splitter is installed to separate the telephony signal from the xDSL signal. Telephones are connected on the one side, while modems/routers or generally CPEs (customer premises equipment) are connected on the other side.

The evolution of technology in xDSL transmission developed new standards like the VDSL2. Using VDSL2, lines may reach up to 100mbps to short loop lengths on single copper lines, while with other techniques like bonding and vectoring the line rate achieves 500mbps. The rate here is also dependent on the loop length; so as it goes beyond the 1.5 Km, rates are similar to ADSL2+. This nature of VDSL2, is the reason of the sub LLU. A remote terminal dslam (RT) is connected usually in the KV, offering the VDSL2 data service to be given on short loops. The backhauling of these network elements is usually done with fiber. Though, the copper transmission techniques of VDSL2 and ADSL2+ cannot coexist smoothly. VDSL2 uses a part of the spectrum of ADSL2+, while at the same time the transmission power is higher. This transmission can be devastating for the neighbor ADSL2+ lines as strong interference is generated between adjustment lines, so it need to be fine-tuned. Although there are decisions of regulation authorities for spectrum management, that tuning is a headache for both operators and regulation authorities, as requires information combination of GIS, CRMs, and network elements in order to conclude to the relevant configuration that has to be applied in order to have the minimum target interference between such services.

The active equipment network topology

The entire above copper infrastructure is part of the telecommunication’s fixed access network. Apart from the copper, it consists of the DSLAM (DSL Access Multiplexers), telephony access gateways or combination of this equipment in an MSAN design (Multi Service Access Node), the copper pair from these equipment up to the subscriber premises and the CPEs (dsl modems/router, SetTopBox etc). The access network end there, and the before mentioned equipment is usually aggregated through SDH or Dark Fiber or Metro Ethernet networks which in part are connected to the core network on the broadband remote access servers (BRAS). In the core network, different application servers and routers are connected, suitable to serve the need of the subscribers for basic telephony services, internet feed and content (IPTV, VideoOnDemand – VoD, Videocall, VPNs etc)

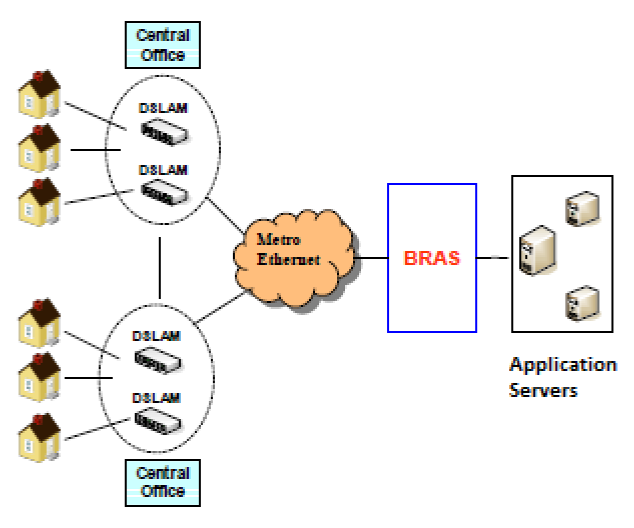


Figure 1: The ISP network infrastructure

xDSL transmission techniques

The traditional landline telephony system is also known as plain old telephone service (POTS). Analog two-wire circuits are used to connect the last mile from the exchange to the telephone in the home (the local loop). Control and audio signals on the same twisted pair of insulated wires. To carry a typical phone call from a calling party to a called party, the analog audio signal is digitized at an 8 kHz sample rate using 8-bit pulse code modulation (PCM). The call, carried over the PSTN using a 64 kbit/s channel, is then transmitted from one end to another via telephone exchanges. Twisted pair lines are used since they reject electromagnetic interference (EMI) and crosstalk better than a single wire or an untwisted pairs.

Adsl transmission uses discrete tones that are modulated to carry information and is preserving immunity to noise with the use of Trellis coding. Standard ADSL uses Descrest Muli-Tone (DMT) transmission with 255 possible tones for downstream and 31 for upstream. DSL signals are made up of multiple modulated carriers spaced at 4.3125kHz intervals across the usable bandwidth. Each carrier is modulated with a certain number user data bits chosen from a set of amplitudes and phases for that particular carrier. The number of bits allocated to each carrier can vary from 1 to 15 bits. Not all tones are used; this depends upon the attenuation of each tone that also affects the number of bit per tone. The main factor for high attenuation is the loop length, thus loop length and available carried information or attainable rate are linked together. Each DMT tone is modulated to appoint in an amplitude phase constellation and the points represent the amplitude of the DTMF tone. The optimum constellation has the greatest number of points for a specified average power, with the minimum spacing between points determined by the level of noise. Trellis coding may be applied before data is mapped onto constellation points to reduce the effect of noise. Trellis coding uses more symbols than needed. The choice of symbol provides additional information about previous data and so reduces the sensitivity to noise. Payload data is carried in 68 of 69 frames that make up a 17msec superframe.

Payload frames contain xdsl channels. An ADSL channel is divided into three main sections:

- a POTS channel, 4 kHz wide
- a high bandwirdth downstream channel up to 2.2 MHz
- a lower bandwidth duplex channel.

Bit allocation table in xdsl terminology is a list of the number of bits being encoded onto each of the available carriers. For ADSL2+ downstream there are 512 numbers in the list covering frequencies to 2.208MHz, from which the first 32 are invariably zero as these frequencies are used by POTS and the upstream signal.

The interference of an adjustent line or of another root cause can deteriorate the signal to noise ratio (snr) for some carriers. In this case the mechanism described by g.992.5 “bit swapping” starts, allocating different carriers to carry the needed information, rather than to the ones with the low snr. Forward error correction is possible to be added to each adsl channel payload to reduce the need for retransmission. Two channel types of adsl can be used: fast and interleaved. The first ensures the fastest delivery of adsl super frames avoiding doing any correction that will delay the packet delivery, while the second ensures a safer data transmission introducing delay. [1]

Forward Error Correction (FEC) and interleaving systems give the DSL technology the capability of correcting corruptions in data transmission. Forward Error Correction is used to correct proportions of errored message data. It is used as a strengthen technique to protect transmission of bursts of noise, named as impulsive noise events. It is done by adding a sophisticated form of checksums to the data transmitted called Reed Solomon checksums. If 10% of the data being transmitted is Reed Solomon checksums then if up to 10% of the received data is in error, those errors can be completely corrected whether the errors occur in the message data or in the checksums themselves. To further strengthen the FEC system interleaving is used. Interleaving consists of a structured shuffling of the data from several FEC data blocks. When the corresponding unshuffling is done in the receiver, the errors caused by a single impulsive noise event are distributed amongst several FEC data blocks thereby increasing the chance that all the errors can be corrected. FEC and interleaving are used together, and a DSL system that uses them is said to be interleaved. The DSL management systems are capable of accounting for the actions of these systems and identifying when corruptions have been corrected.

Data frames contain 8-bit Cyclic Redundancy Check (CRC) bytes. The size of the data frames used depends on many optional configurable parameters of the ADSL connection. The CRC covers just the message data to be sent and is calculated without including any FEC overhead and before interleaving and scrambling take place. If when the CRC is recalculated at the receiving end it is found to check correctly it is highly probably that all the message data is in fact correct. Equally if it fails to check correctly it is highly likely that the message data has been corrupted, despite any FEC and interleaving that may have been implemented. When a CRC fails to check correctly, this is commonly known as a “Code Violation”. [2]

A VDSL2 system can utilize frequencies up to 30MHz and theoretically deliver up to 100Mbit/s in both upstream (toward the network) and downstream (toward the customer) directions. Similar to ADSL2+, VDSL2 is based solely on discrete multi-tone modulation (DMT) and uses frequency division duplex (FDD) in order to avoid near-end crosstalk (NEXT) noise between VDSL systems. As FDD is used the DSL systems’ performance is typically restricted by the far-end crosstalk (FEXT) interference. In a scenario where service is given both from LLU and sub LLU, special care must be taken into consideration regarding the configuration management as far as service and spectrum settings. PSD masking / shaping, downstream / upstream power back-off are the techniques to assure the quality of the offered services.

ITU standards G998.1 and G998.2 provide details for bonding DSL pairs at either the ATM or the Ethernet layers [3], [4]. Bonding is effectively the parallel use of DSL pairs to improve throughput. It is the data channel over the multiple pairs that actually is bonded and not anything at the physical layer. The throughput of a set of n bonded DSL pairs is approximately the same as n times the throughput of any individual pair alone. As multiple pairs are in use it is highly likely that they will be in the same cables from source to destination. As such, each pair will be subject to at least some common sources of crosstalk (the same “other” disturbers in the same cables). Use can be made of this to cancel these sources of crosstalk/interference in the vectored receiver. Further, most of the crosstalk experienced in the vectored receiver may be due to other transmitters in the bonded set; therefore this crosstalk source can be even more effectively cancelled out since it can be predicted absolutely, once the crosstalk paths are analyzed. As a result of vectoring, bonded systems can yield throughputs that are in excess of the sum of the individual throughputs of pairs making up the bonded set.

Summarizing the transmission techniques, some quick assumptions are the following: the use of a much wider frequency spectrum comparing to telephony, is the reason why the data services are more sensitive comparing to voice. Furthermore, lines with low copper length achieve higher quality services and rates compared to longer ones. So, the complexity of the spectrum configuration is a challenge for services over copper, in order to give the possibility to serve high end bandwidth demanding applications (like multiple channels of IPTV) over the same old copper pairs, for the majority of the subscribers.

As the nature of these services is packet based, the need is to serve them with minimal or controlled packet loss. Taking into consideration that packet loss is the effect and not the root cause of the problem, what is needed for troubleshooting and isolating the root cause, turns up to require hours of investigation.

Copper network assurance

From test heads to sophisticated chipsets

In the first developments of local loop, operators in order to troubleshoot the copper condition or the telecommunication equipment had to go on field with specific instruments capable of performing a series of tests. As the order of the troubleshooting, at first, requires a check on the local exchange, operators in order to gain time and money used to purchase high cost test heads, that were intermediate connected between the dslam / pots access gateway and the local loop. These test heads, upon demand, were partially disconnecting the local loop from the equipment, measuring the loop condition, or disconnecting the loop in order to test the equipment behavior. Vendors understood that demand and integrated in their chipsets the majority of these troubleshooting mechanisms. International organizations like ITU and IEEE defined also some standards regarding the testing methods and results. Furthermore, specific statistical data are kept in several system levels on the networking equipment, allowing someone to export from statistics performance data for the given service.

Though, each of these measurements is done in an ad-hoc manner. Usually all these actions are retroactive upon some customer complains. Operators in these cases have to hurry, in order to solve the problem in the given SLAs, keeping happy their subscribers and maintain low churn values. Technicians that handle such cases have to be highly experienced in order to perform the right action that will save time towards the problem resolution, while maintaining low operational expenses. The biggest problem for these technicians is at first the fault identification and secondly the fault localization. All these on the other hand, jeopardize business projections, as it seems as a contradiction: occupying highly educated personnel to handle big amount of customer complains is expensive. Not occupying such personnel, leaving the same job to be done by other low experienced engineers will lead to the worse results: high resolution time, truck rolls that are not needed, churn.

Copper Pair Diagnosis

It is essential for an operator to integrate in the lifecycle workflows the different line testing mechanisms – tools, in order to leverage the OPEX and make the best benefit out of the business. These tools can be used in the pre-provisioning to guarantee the construction of a pair from the local exchange up to the subscriber premises. Then, mechanisms must be adopted in order to qualify a line, for the offered service a subscriber has purchased. Upon the qualification, several actions can be addressed apart the relevant configuration management, targeting to maintain the given quality and act proactively on possible faults. Such tools and techniques incorporate the NarrowBand Line Test, SELT, DELT and Performance Counters.

The NarrowBand Line Test (NBLT) is initiated by the telephony access gateways in order to qualify the copper pairs using electrical characteristics. SELT is a relevant test, used to identify specific copper faults and perform predictions on the possible service a subscriber may have. DELT is a real time service monitoring of the synchronization parameters of a line. DSL performance counters are statistics, that contain physical and channel information regarding the service and can also be used to qualify lines without service disturbances. SELT, DELT and DSL statistics are tools initiated from the DSL CO equipment or DSLAM.

NarrowBand Line Test (NBLT)

This test is executed by POTS and ISDN equipment that serve the tdm-like voice service. It may be in a form of test set, measuring the physical characteristics of copper pairs, interrupting partially the offered service.

In telephony equipment, the terms that represent the conductors of the telephone circuit are named as A and B tip and ring, while earth/ground is represented as G. Tests in NBLT are performed between the two conductors or one of the conductors and the ground.

Foreign Voltage

The first set of test we may find on the NBLT is the foreign voltage set. That means the examination of foreign DC and / or AC voltage on the pair. The only source of voltage must be the central office, so the equipment by isolating the feed of the pair can detect if the problem exists. The foreign DC voltage tests are the

- DC Voltage A to B, the Continuous Voltage between A and B
- DC Voltage A to G, the Continuous Voltage between A and ground
- DC Voltage B to G, the Continuous Voltage between B and ground

Usually, service has no impact with ±3V DC. Excessive voltage more that this amount, in telephony, creates noise in the good case scenario and may end up to complete service loss, depending on the voltage tense. In the dsl service, external dc voltage causes noise and additional attenuation, factors that affect the synchronization speed and the bit error rate. The root cause of such a fault, can be wet sections of the copper pair, typical cross problems (when one or both wires in a pair cross with one or both wires of another pair) or physical damage on the pair, like bad connectors on splicing points or oxidation.

Except the DC we may find AC external voltage. The tests that identify it are the following

- AC Voltage A to B, the Alternate Voltage between A and B
- AC Voltage A to G, the Alternate Voltage A and ground
- AC Voltage B to G, the Alternate Voltage between B and ground

A small amount of electrical energy can also be tolerable (up to 3 V A to B, up to 10V A/B to G), though more energy that on the pair causes similar effects as described above: extensive noise, degrading the quality on telephony and dsl transmission. This test is handled separately of the previous, since the root causes of the problem cannot be the same. This voltage can found when nearby power lines induce energy on a copper pair.

Resistance tests

A conductor properly constructed must not have any electrical pat to ground. The tests in order to identify this are:

- Resistance A to B, this test measures the Resistance between A and B

- Resistance A to G, this test measures the Resistance between A and ground
- Resistance B to G, this test measures the Resistance between B and ground

Resistive faults affect the balance of the copper pair. In case of an unbalanced pair, the conductors cannot reflect noise and the quality of the transmitted signals is low. In terms of telephony, the service can be served with a lower resistive quality pair, around 200kOhm is enough, though, in case of an xdsl line, typical resistance values must be higher than 1MOhm. The root cause of such a problem can be a wet section or generally cable damage that can create resistive path for the current to flow.

Capacitance tests

Capacitance is used in many cases to predict the copper length. Usually the capacitance from a pole to ground divided by 52 gives the pole length. Note that a wet section that may add extra capacitance. The tests that may be executed are:

- Capacitance A to B, the Capacitance between A and B
- Capacitance A to G, the Capacitance between A and ground
- Capacitance B to G, the Capacitance between B and ground

In case there is difference between the values of the poles to ground (more than 1%), the loop is unbalanced. That means noise on the line. The root cause can be a bridge tap that is connected on parallel with the one or two poles.

Card self tests

There are several other self tests integrated in each equipment that guarantee the proper voice service, like loop current, battery feed, dialing, on/off hook detection, dc feed metering self test etc. All these do not actually present the condition of a copper pair, but give the availability of the equipment to work as it should be, avoiding hardware faults located at the central office.

SELT

SELT or Single Ended Line Test, is a set of measurements initiated from the DSLAM. Due to its importance in the dsl pre and post provisioning, ITU-T did an effort to standardize it as G.SELT. In ITU-T standardization, a layered approach has been followed. The following scheme represents these layers and the interfaces between them.

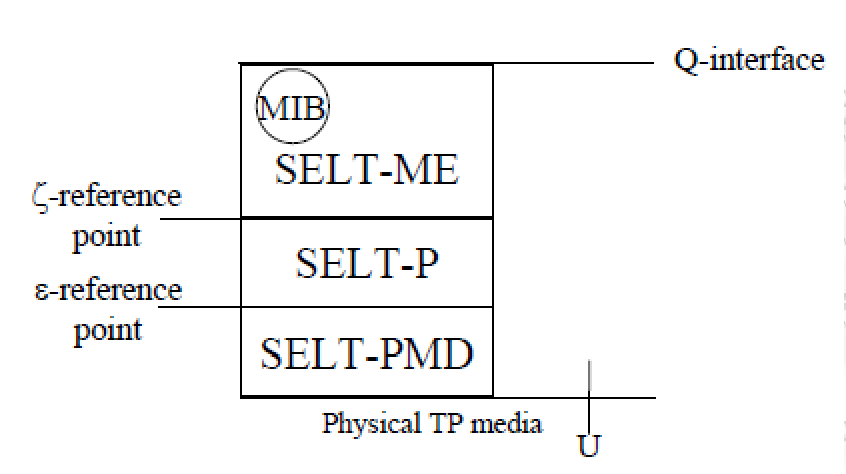


Figure 2: The G.selt functional model agreed to at the October 2002 ITU meeting

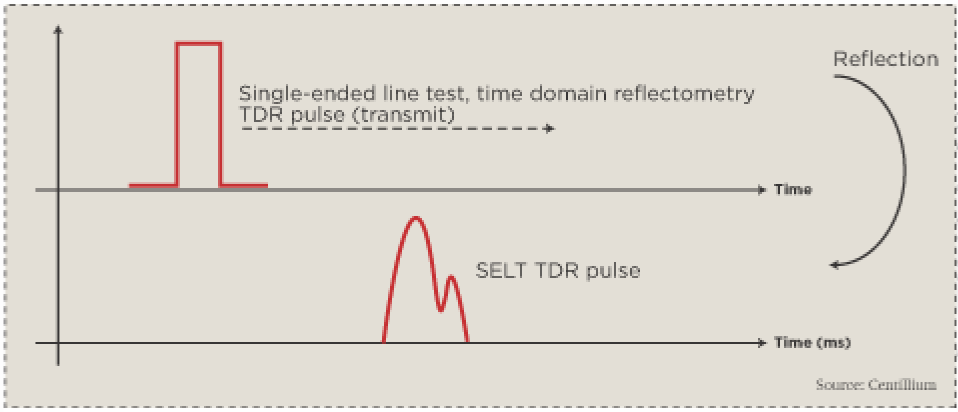
The functional model consists of three layers.

- The SELT-PMD (single-ended loop test – physical-medium dependent) function performs measurements on the physical medium to which the G.selt device is connected. Two types of measurements can be distinguished: measurements that are associated with an excitation of the physical medium by the functional block and measurements that do not require excitation. The result of a measurement is a quantity, represented as a parameter (one- or more dimensional, discrete or continuous). From these parameters, “secondary” parameters are derived, usually through multiple measurements. An example of such “secondary” parameters may be the echo impulse response.
- The middle functional block is called the SELT-P (single-ended loop test – processing). The SELT-P function transforms the secondary parameters into parameters defined in the MIB. These MIB elements, so-called “primary parameters,” directly reflect the characteristics of the loop under test. Examples include: topology of the loop, loop make-up, noise on the loop.
- The third functional block is denoted SELT-ME (single-ended loop test - management entity). The SELT-ME manages the Management Information Block and communicates with the OSS over the Q-interface. [5]

SELT measurement techniques

Some of the standard measurement techniques that are used in SELT include:

- Time-domain reflectometry (TDR): Time domain reflectometry is perhaps the oldest measurement used for SELT in telephone lines. A rectangular pulse is transmitted across the channel; the reflected pulse is then examined for time characteristics. The shape and delay of the reflection(s) contain information about where various impedance mismatches occur. The reflection can be used to determine the length and gauge of the wire. To assist with weak reflections and mitigating the effects of loop noise, typically a train of impulses is used and the reflections are averaged.



Time domain reflectometry is perhaps the oldest method used for single-ended line testing in telephone lines in which a rectangular pulse is transmitted across the channel. The reflected pulse is then examined for line characteristics.

Figure 3: Time Domain Reflectometry [5]

- Frequency-domain reflectometry (FDR): The loop is sounded with a swept sinusoid with varying frequency that is transmitted and measured for loop response at each frequency, in order to identify frequencies that either resonate or are “dead.” For example, peaks in the measured receive signal correspond to frequencies that create standing waves. Standing wave frequencies provide information about the length of the cable.
- One-Port Scattering Parameter: This method is similar to FDR, but instead of looking for individual frequencies, a complete echo response measurement is utilized. From the echo response, the input impedance of the loop can be determined, from which the loop topology can be determined.
- Power spectral density (PSD) of noise on the line: In this measurement the transmitter is quiet, and the modem measures the loop noise present.

While the measurement techniques all contain identical information about the loop, there may be advantages to one technique over another during the analysis phase. The advantages depend upon the preferred algorithm(s) in use in the analysis engine and the parameters associated with the various measurements (e.g., sampling rate, start and stop frequencies, etc.). It is certainly possible that a given analysis engine may request more than one type of measurement be taken to improve the overall accuracy of the resulting estimate(s).

SELT Processing - Data Analysis Engine

The data analysis engine is responsible for using the SELT measurements to estimate a variety of parameters and DSL capabilities associated with the loop, including:

- Loop Topology - loop length, bridge taps length/number. Also important is the potentially unknown remote termination impedance. Generic loop topology models, consisting of segments, each with its own length and gauge. The objective of SELT is to provide the operator with an estimate of the loop topology that mimics the actual topology as closely as possible. Estimating the loop topology is a multi-variate optimization problem whose complexity will depend upon the accuracy and range requirements as well as the number of unknowns.
- Loading Coils - detection and location(s). Where they still are used, they are typically deployed with fairly strict design rules. Again, if the analysis engine knows if loading

coils are allowed, and, if so, how they may be present, algorithm complexity can be eased.

- Loop Attenuation/Insertion Loss – having estimated the loop topology parameters, the attenuation/insertion loss of the loop can be computed. This calculation is fairly straightforward and simple.
- Crosstalk profile – using the measured near-end loop noise PSD, an estimate can be made of the type and number of crosstalkers present. Again, this is a multi-variate optimization problem.
- Far-end loop noise – using the estimated crosstalker profile, an estimate of the loop noise present at the far end can be made. However, many assumptions are required to perform such an estimate. It is unclear at present how accurately far-end loop noise estimates can be made. Clearly, the accuracy will depend upon the bandwidth over which near-end PSD measurements are taken. Many existing CO DSL modems may only support a relatively narrow receive frequency range, which will increase the difficulty of estimating the much wider bandwidth far-end loop noise.
- Achievable downstream and upstream data rates – with an estimate of the loop attenuation and near- and far-end noise, an estimate of the achievable downstream and upstream data rates can be made. However, even if all previous SELT estimates are perfect, an estimate of the achievable data rates can only be approximate, as it depends heavily on chipset vendor, chipset version, modem model, software version, etc.

SELT Management Entity - Data Distribution

The final step for SELT is the distribution of the estimated parameters via a MIB into the Operations Support System (OSS). It is necessary to integrate the control of and the results from SELT into a form that can be used at the same time by customer sales representatives, support representatives or craftspeople, provisioning and accounting processes. This level of integration with the significant value this tool can provide, can only be realized in a cognitive approach.

SELT leads the way to the OPEX reduction of the xdsl lifecycle. It minimizes useless truck rolls to provide verification that a DSLAM port is physically connected to a loop. It provides with relatively low complexity details regarding the loop condition of a subscriber, pre-qualifying at the same time the purchased service for the data rate. Upon those results, the appropriate settings can be selected for the line in order to provide a stable service and keep the subscriber happy. Bridge Taps that are distorting the service are easily depicted. Service disruption like disconnections of the loop, physical breaks in the loop, RF interferences, changes in loop noise, equipment failures, etc. can be detected by comparing the current loop topology estimate against previous saved estimates.

DELT

The ADSL2 standard has provisions for dual-ended loop testing (DELT), using coordinated transmission and measurement between the CPE and CO modems. DELT does not require that the modems be capable of achieving data transmission and is a fairly robust tool, that could certainly be used for post-service activation problem solving. DELT test results formulate a table, whose most important results are stated below:

- **adsl2SCStatusSnr**: The SNR Margin per sub-carrier, expressing the ratio between the received signal power and received noise power per subscriber. It is an array of 512 octets, designed for supporting up to 512 (downstream) sub-carriers. The number of utilized octets on downstream direction depends on NSCds, and on upstream direction it depends on NSCus. NSCds/us is the highest sub carriers index which can be transmitted (i.e., sub carrier index corresponding to Nyquist frequency.

- **adsl2SCStatusBitsAlloc**: The bits allocation per sub-carrier. An array of 256 octets (512 nibbles), designed for supporting up to 512 (downstream) sub-carriers. The number of utilized nibbles on downstream direction depends on NSCds, and on upstream direction it depends on NSCus.
- **adsl2SCStatusGainAlloc**: The gain allocation per sub-carrier. An array of 512 16-bits values, designed for supporting up to 512 (downstream) sub- carriers. The number of utilized octets on downstream direction depends on NSCds, and on upstream direction it depends on NSCus.
- **adsl2SCStatusTssi:** The transmit spectrum shaping (TSSi) breakpoints expressed as the set of breakpoints exchanged during G.994.1. Each breakpoint is a pair of values occupying 3 octets with the following structure: First 2 octets - Index of the subcarrier used in the context of the breakpoint. Third octet - the shaping parameter at the breakpoint.
- **adsl2SCStatusLinReal**: An array of up to 512 complex H(f) linear representation values in linear scale for the respective transmission direction. It is designed to support up to 512 (downstream) sub-carriers. The number of utilized values on downstream direction depends on NSCds, and on upstream direction it depends on NSCus.
- **adsl2SCStatusLog**: An array of up to 512 real H(f) logarithmic representation values in dB for the respective transmission direction. It is designed to support up to 512 (downstream) sub-carriers. The number of utilized values on downstream direction depends on NSCds, and on upstream direction it depends on NSCus.
- **adsl2SCStatusQln**: An array of up to 512 real Quiet Line Noise values in dBm/Hz for the respective transmission direction. It is designed for up to 512 (downstream) sub-carriers. The number of utilized values on downstream or upstream direction depends on NSCds and NSCus
- **adsl2SCStatusLnAtten**: When referring to the downstream direction, it is the measured difference in the total power transmitted by the ATU-C and the total power received by the ATU-R over all sub-carriers during diagnostics mode. When referring to the upstream direction, it is the measured difference in the total power transmitted by the ATU-R and the total power received by the ATU-C over all sub-carriers during diagnostics mode.

The bit allocation information can be used to great effect. In principle the set of bit allocations is almost like a spectrum analyzer reading of the noise on the line, since the allocation to each carrier says something about the noise at the frequency of the corresponding carrier. The information of the bit allocation table, the magnitude of the signal sent and on the attenuation of the loop is also known and therefore an estimate of noise v frequency can be derived. With the noise v frequency estimate, it may well be possible to determine the nature of the source of the noise

The interpretation or analysis of these results can lead to significant results regarding the copper loop condition. Noise characterization is required to be able to configure modem parameters to combat the potential for transmission errors and/or achieve the highest transmission rate possible. Modems are designed to measure continuous noise, e.g. crosstalk, RFI, as a function of frequency and use this characterization to set modem parameters for a defined minimum signal-to-noise margin to maximize transmission rate up to a specified maximum and then to reduce transmit power. For example RFI being picked up from nearby radio stations could be implied if the noise graph has peaks in it at frequencies corresponding to nearby AM radio transmissions. If excessive, this could be indicative of poor network balance, either due to poor customer premises wiring, or (less likely) poor access network condition. If the variations in the noise shapes are not spikes but smooth transfers with characteristic notches and edges, it can be assumed that this is due to crosstalk being picked up from identifiable other DSL systems such as ISDN, ADSL, or SHDSL.

Performance Data

When a DSL modem system starts up transmission it is said to be an “initialization”. Full initialization happens if the power is down and a “warm start” if the link has been temporarily suspended by a management action. Failure to initialize can be due to powered off CPE, to a line cut, to excessive noise, or to a service level that cannot be guaranteed as applied by the configuration profile of the line. In case a link is up and goes down unexpectedly, it this to reinitialize. This is called a retrain event. In case the link cannot come up, the retrain is characterized as failed. In the xDSL systems, there are counters that provide the initialization and retrain events. Furthermore, the DSL protocol allows the transmission of a “dying gasp” management message, in the remaining capacitor-fuelled few milliseconds of operation, after a power fail on the remote modem. So, if an initialization happens and no dying gasp message has been arrived assumes a problematic behavior either of the copper pair or the modem’s connected to it. [6]

A FEC second is a second in which at least some data has been corrected by the FEC system. An errored second-ES is a second in which at least one code violation occurred. A severely errored second is a second period during which there was a major error such as an out of frame condition, or a bit error density greater than 10^{-2}. A period of 10 continuous severely errored seconds cause loss of synchronization; that time a counter starts regarding the unavailability of the service, named UAS – unavailability seconds.

There are also alarms or events describing the link situations.

- LOFS (loss of frame seconds) - Counts accrued after loss of frame detected. An Out of Frame event occurs when four consecutive frames do not contain a valid frame word. A Loss of Frame defect is initially triggered when an Out of Frame (see OOF) condition occurs and doesn't clear for more than 3ms
- LOSS (loss of signal seconds) – A LOS defect may initially be triggered when all zeros are received for 20 microseconds which starts the integration period. During the integration period, 2 consecutive frames with 20 microseconds of signal loss will record a LOS event.
- LPRS (loss of power seconds) – When power is lost for some period of time

Uptime value is the total time that the link has been operating in full service, usually as a second count over a 24 hour period, with a maximum of 86400. Lack of up time can be due to modem being turned off of not being able to initialize. Uptime can be used to gate the validity and significance of other data. [6]

There are various types of counters specified in the Management Information Base (MIB) of the xDSL. Each of the described above counter refers either to the line, or to one of the bearer channels.

lossOfFrameEvents	Line
lossOfSignalEvents	
lossOfLinkEvents	
lossOfPowerEvents	
erroredSeconds	
severelyErroredSeconds	
unavailableSeconds	
initializationEvents	
fastRetrainAttempts	
failedFastRetrainAttempts	
codeViolations	
forwardErrorCorrections	
forwardErrorCorrectionSeconds	
lossOfSignalSeconds	

transmittedBlocks	Channel
receivedBlocks	
correctedBlocks	
uncorrectedBlocks	

Figure 4: Line and Channel performance data

In the xDSL mibs, the generation of these counters is in a 15 minutes intervals or periods. Several intervals may be stored upon each element, while a 24hours counter is generated by the aggregation of the several 15 minutes counters.

Service configuration management in xdsl equipment

In ideal conditions where no noise or crosstalk would exist, all lines would have the same configuration settings on the DSLAMs. This cannot happen and there is a tradeoff between low delay, high rate lines and stability.

Configuring the service parameters of an xDSL channel, there are separate parameters both for downstream and upstream, that need to be taken into account.

The most important parameters that have to do with the data rate settings and the behavior of the line against noise are the following:

- Minimum Data Rate: Each line has an attainable rate, upon its loop length, crosstalk and other conditions. Given the desired service, the operator may want to guarantee a Minimum Data Rate lower that which the service will not be acceptable and the relevant modems will not synchronize.
- Maximum Data Rate: The limit of the synchronization rate imposed by the operator. This limit is applied either because of the rate limiting policy of the operator, or to minimize the crosstalk to adjustment lines, if the applied one cannot achieve higher rates that the maximum data rate.
- Maximum Bit Error Ratio: The minimum bit error rate that has to be maintained for the successful delivery of the service

- Target Noise Margin: The target signal to noise ratio that has to be followed in order to achieve the maximum Bit Error Ratio.
- Minimum Noise Margin: Once a line is synchronized and the crosstalk conditions change to the worse in a given time, if the SNR reaches the Minimum Noise Margin, the dslam is instructed to re-initialize the line.
- Maximum Noise Margin : Once a line is synchronized and the crosstalk conditions change to the better in a given time, if the SNR reaches the Maximum Noise Margin, the dslam is instructed to reduce its transmit power in order to eliminate the crosstalk that will affect other lines.
- Maximum Interleaving Delay : The depth of the interleaving function expressed in time units
- Minimum Impulse Noise Protection: In case of impulse noise, the minimum symbols that can be corrected from CRC errors

Energy consumption and configuration management

New obligations for the telecommunication operators are now days imposed by regulation authorities that have to do with the energy consumption of their equipment. This energy waste management demands have been translated into configuration settings for the xDSL profiles. Different power levels have been defined as following:

- L0 – normal operation of full power
- L2 – low power operation maintaining link synchronization
- L3 – no power consumption with lines not connected

Applying the different power levels means that the DSLAM or the management system is monitoring the bit loading and the SNR in every line. If nothing is changed, the CPE and DSLAM cannot reduce the transmit power. Though, if the bit loading starts to deteriorate along with the gain it the relevant carriers, the power needed to transmit the initial bits is considered as waste as no longer used, so the dslam falls to L2 power level for the downstream direction. In case the line has no CPE on the other side, only a steady pulse of low power energy consumption is transmitted in order to detect a remote end device. This is the L3 mode of the DSLAM, where minimum energy is consumed.

The configuration profile parameters for the L2 power management are the following:

- L0-TIME: The minimum time between Exit from the L2 state and the next Entry into L2 state
- L2-TIME: The minimum time between Entry into the L2 state and the first Power Trim in the L2 state and between two consecutive Power Trims in the L2 State
- L2-ATPR: The maximum aggregate transmit power reduction that can be performed at
- transition of L0 to L2 state
- L2-ATPRT: The total maximum aggregate transmit power reduction that can be performed in an L2 state

A more comprehensive approach on these parameters is explained with the scheme below

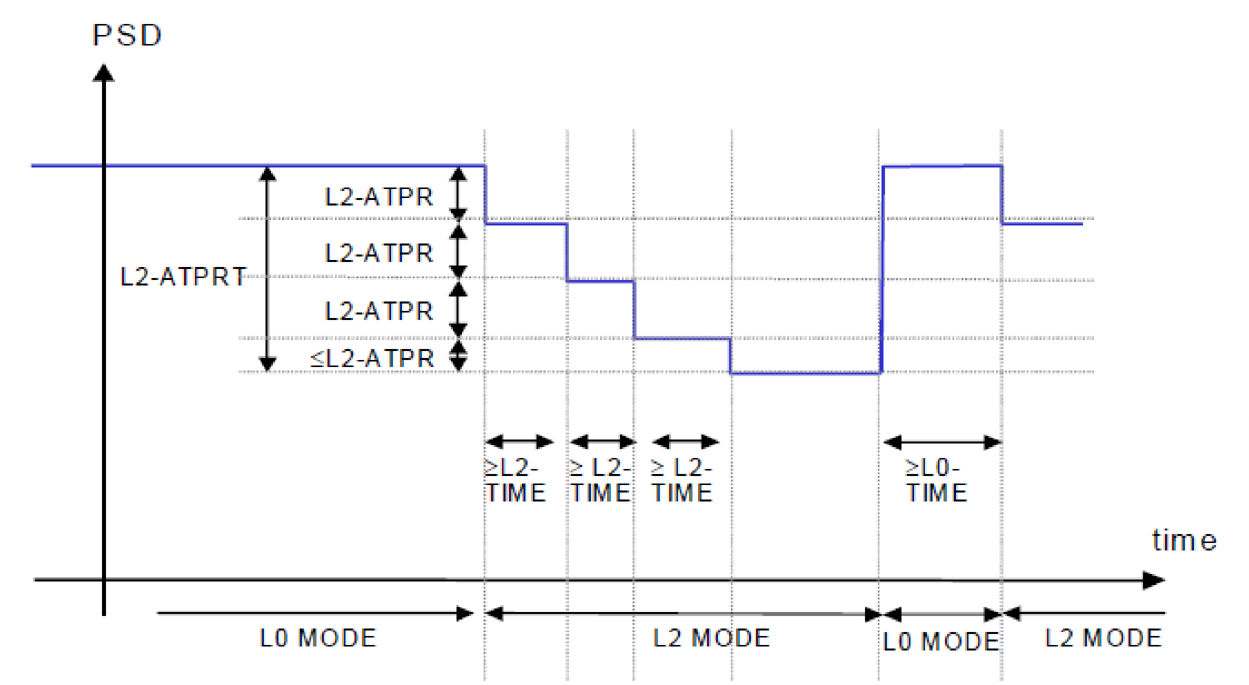


Figure 5: The power level operation [7]

Once a line operates at L0 mode and for a period of time greater than the L2-TIME, the conditions that instruct for a L2 mode have been met, the dslam shall reduce its transmit power for L2-ATPR db. The power level can be reduced even further up to L2-ATPRT, in steps of L2-ATPR, if again the requirements described above have been met, in steps of time greater that the L2-TIME. [8]

Some recommended values [8] have been calculated to result in a power saving of the order 75% of that achievable using the most aggressive power saving parameters but with a much reduced impact on DSL performance (by virtue of the fact of the increased damping in the control system which minimizes the fluctuating crosstalk).

VDSL and spectrum configuration management

Telephone cables typically contain many individual ‘pairs’ grouped together in ‘binders’. The arrangement of binders within cables can be pictured as ‘smaller cables within a bigger cable’. As mentioned before, the rate limiting factor in xDSL is crosstalk interference coming from other lines in the same binder, which degrades the signal received by a ‘victim’ receiver. Interference degrades the Signal to Noise Ratio (“SNR”) thereby reduces the capacity. In case of emission of ADS2+ only signals when the dslams are located in the CO, crosstalk can be cancelled using techniques that evolve the autonomous power allocation. This can be achieved by just applying to each line an appropriate profile that has as maximum rate the rate a line may achieve.

Though, the so promising VDSL2 technology when deployed in a scenario of coexistence with ADLS2+ interferes in a high scale towards the previous technology, as its power spectral density in the overlapping frequencies is much higher. Taking into consideration the fact that VDSL is mainly installed in remote cabinets, the typical loop length of a vdsl subscriber is much less than the one of an ADSL from CO subscriber, the impact over the ADSL service is very big as its performance significantly degrades. Several techniques have been invented to reduce the VDSL (or XDSL cabinet emitted) signal to a level similar to the attenuated ADSL2+ signals from the cabinet. Not for all frequencies used for VDS2 the PSD applies. This is done usually up to a maximum usable frequency, after which the signal emitted from the CO(Central Office) is so attenuated that the benefit of using there frequencies is practically not considered important. The drawback of such techniques is the rate reduction in VDSL2, as the frequency range up to the level of the PSD shaping is used with low power, thus low snr and bit loading. As it is obvious, the reduction of the VDSL is lower when the remote cabinet is far away from the CO and higher when it is closer.

The complexity is getting higher, due to the existence of different band plans for VDSL2. There are some cases where the overlapping spectrum is the downstream of ADSL2+ with the one of the VDSL2, others where apart from that the upstream spectrum is also overlapping and others where the upstream and downstream of ADSL2+ overlaps with the downstream of VDS2.

As development of VDSL2 is not in every operator’s business plan, the waterbed effect of this problem is usually solved from the regulation authorities. The selection of the possible operating band plans is also a regulation decision. The waterbed effect of the loss either in ADSL2+ or VDSL2 is a compromise of a value either expressed as “protected line rate”, or as the cabinet’s “insertion loss” expressed in dB of attenuation. Whichever of these two ways will be followed, there is always a problem for the operators the definition and the provisioning of the appropriate profiles applied on each line, in order to adopt the regulated PSD. Also the estimation of which PSD mask must be adopted in case of a new cabinet deployment is also a complex and expensive procedure.

Summing up, except of the service or rate parameters, the line spectrum profile must be set in the DSLAM settings. Parameters therefore like the power levels on a frequency basis per cabinet bases have to be configured and this requires deep involvement of a per line case of high educated engineers and the use of additional systems that combine inventory in a geographical aspect.

Services and content over broadband

The copper network was initially used for voice services. Our well known Internet network appeared and the same network was used to connect subscribers to the “internet world”, while having at the same time as “primary” service the telephony. The offered services were subscriptions for telephony service and internet access at or up to a specific xDSL line rate. As the coverage over the population was spreading and the competition went rougher, the limit of the xDSL service was offered as a service: “up to 24Mbps”.

With the vast usage of internet in work, leisure and every aspect of our life, new demands appeared. The internet access is not any more the target of the subscription. What differentiates the ISPs is the offered content over the existing internet access:

The first form of content was value added services with internet telephony. Our analogue voice is packetized in specific sampling rates that produce standard acoustic quality. Depending of the quality needed some decades of kilobits per second is needed for that service. The nature of internet telephony as a real time service demands accurate timely delivery of packets without delay or retransmissions. Operators are used to offer either embedded of the modems or separate devices (Analogue to Terminal Adapters) that have to be properly configured in order to realize their Voice over IP protocol service, so called VoIP.

Subscribers were enjoying advanced telephony services and video-telephony appeared. The few decades of kilobits per second are now a few hundreds. The higher bandwidth demands impose a headache on the asymmetry of the adsl service since a very good video quality requires bit rates close to the 1mbps of technology’s limitation. Relevant devices compared to the previous categories are also needed.

The transport of low quality real time video of the video-call evolved to video services. IPTV is the term for broadcasting video over the IP network. Subscribers over their operator’s controlled SetTopBox are possible to see live a broadcast service of a provider, of purchase on demand a favorite video stream like a movie, controlling by their own the video flow. The transport of IPTV requires low bit error rate and jitter, though it can have a higher delay than voice. All these aspects have to be maintained in the delivery of the bandwidth demanding video stream. The initial downstream net throughput demand of a standard definition video stream was at 5mbps though with the video encoding evolution this decreased to the half. On the other hand, subscribers required watching multiple channels at the same time. As the 6 plus 20% overhead mbps required for internet and standard definition TV (2 channels *2mbps + 2mbps internet) can be offered in an increased majority of the households in the majority of the urban world, the appearance of high definition TV has messes things up. As 8mbps synchronization is required only for one high definition channel, the coverage of this service is considerably lower than the standard definition TV.

Regardless from these services, users and their behavior impact also the potential services of the operators. Online gaming requires in contradiction to IPTV the minimum possible delay to be imposed on the network. Business critical applications should be consider having a more guaranteed transport, not in terms of networking QoS (Quality of Service) as in fine tuning of the transmission techniques.

Managing Customer Premises equipment

Managing the customer premises equipment is a one-way road for operators that want to offer something more than just internet access. The cost and the effectiveness of this concept were in the early development of broadband services tremendous. Broadband forum did an effort to standardize a communication protocol between the end users devices and a management server, named as ACS – Auto Configuration Server. The new protocol named CWMP stands for CPE WAN Management Protocol has been initially described for xDSL routers in Broadband’s forum technical report TR-069. The protocol is at the application layer and defines a bidirectional SOAP/HTTP-based communication between the CPEs and the ACS. It includes both a safe auto configuration and the control of other CPE management functions within an integrated framework.

The expand of the need of managing something more than the xDSL CPE, in addition with the complexity of the non-homogenous customer devices, caused the generation of several additional TRs. As a result, there have been issued:

- TR-098 for QoS
- TR-104 for VoIP Gateways and Analog to Terminal Adapters
- TR-106 for digital home devices
- TR-110 for VoIP configurations
- TR-111 for LAN/NAT devices
- TR-135 for Set Top Boxes
- TR-140 for Network Storage
- TR-142 for PON devices
- TR-156 for GPON access
- TR-196 for Femto access.

With the use of CWMP, operators benefit in many ways. Regarding the provisioning of the subscriber devices, a “Zero Touch” approach has been possible, requiring no dispatches from the operator but just the cabling connection done from the subscriber. The ACS server configures remotely, as predefined from the operator, the remote networking or home entertainment equipment.

The remote management of the devices is crucial in case of the deployment of new services. This is feasible through CWMP, using remote configuration scenarios. Furthermore, CWMP gives the possibility to load massively bug fixes or firmware upgrades in a vast of controlled devices. The control can be defined into groups whose criteria are also defined by the operator. Inventory management can also be done from the ACS regarding the controlled devices, applied in possible groups as described before. The device management solution offers the ability to remotely monitor the CPE's operation and health status. This can include triggering of notifications and other workflows upon events. For example, if the user changes a CPE parameter that violates a policy, and an event can be triggered to restore the parameter setting to its authorized value. [6]

Managing the end devices gives a further advantage to operators who want to differentiate applying methods for monitoring the Quality of Experience. As these devices are on the end side, the QoE is been monitored there. Statistics can be collected, analyzed in Key Performance Indicators (KPIs), qualifying the experience of the subscriber who receives the given service.

Value of GIS for configuration management of xDSL

As the deployment of VDSL2 is on its way and regulation authorities try to balance between the already not capitalized investments and the deployment of new technology, the value of GIS systems is of a paramount importance. The regulation that has to be performed regarding the PSD shaping on a per cabinet basis is a trouble and highly expensive exercise that has to be done in a per cabinet case.

The use of GIS systems can make things easier, admitting that lines, whose terminating points are on a very short distance, are probably served from binders that pass from the same cabinet. Lines that start from the same dslam, travel from the binder path, and end up at close points among them, have about the same attenuation, and are imposed about to the same interference and noise. As a result, modeling the condition of loop quality, determines in a possible location the loop condition. In reality there are enough factors that can make a line not to follow that boundaries, though the root cause of these problems are typically located after the cabinet towards the subscriber, but if not that percentage is really low.

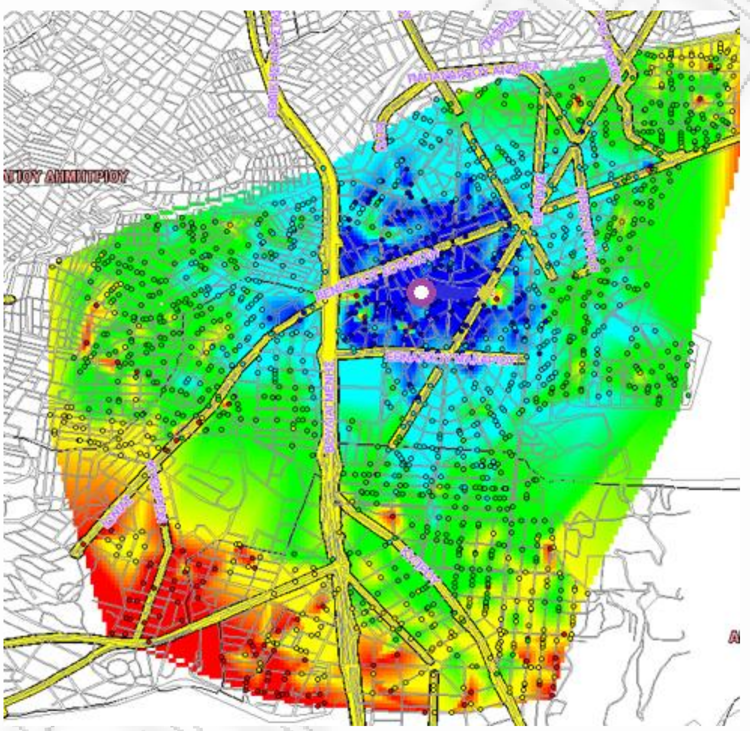


Figure 6: A GIS color rate aspect on a local exchange

Geographical Information Systems may use spatial interpolation methods to estimate the values of properties at unsampled sites within the area covered by existing observations. Assuming that a property is the cabinet deployment of VDSL2, value to be the insertion loss of that cabinet, or the attainable bit rate, observations to be synchronization parameters as the line attenuation, the bit rate, the maximum usable frequency, the appropriate values shall be calculated by the GIS system and the relevant PSD mask and xDSL profiles can be generated for each line in the cabinet.

A solution tailored to VDSL2 PSD masks requires a Digital Terrain Model - DTM application to be implemented in the GIS system. The DTM components are data acquisition, functional requirements and data structures. Data acquisition must be a near real time information database that combines the geographical information of every central office, cabinet and subscriber, along with the xdsl synchronization parameters of each instance. As data structure of DTM through DELT and SELT can provide inspections that modelized the noise on every possible geographic location. The functional requirement on the DTM is the generation of the PSD mask for every location on the boundaries of each central office. [10]

Part II: Cognitive management in access networks

Management Systems Evolution

It is obvious that each copper pair has a unique different situation in terms of construction quality, time varying interference, and loop length. Furthermore, different services or applications require different impulse noise protection schemes, different rates, delay etc. Therefore provisioning, operation and troubleshooting of xDSL services is a complex task. The critical factor for the operator, is to find the combination of all these parameters that shall guarantee the finest quality of the purchased service to the given subscriber, to maintain low operational costs, while at the same time evolve in a behavioral model it's product over with innovative services. Successful targeted pre-provisioning of all networking equipment, monitoring and qualification of statistics analysis of the given service; proactive actions in terms of reconfiguration needed are some of the goal of the system management and engineering in every operator.

The design of traditional management systems in broadband networks has been adopted following the Telecommunication Management Network (TMN) protocol model. The TMN was introduced by ITU-T Recommendation M.3000 in 1985 as a reference model for the Operation Support System (OSS) of telecommunications service providers. It is a model which incorporates a framework for the interaction of heterogeneous networks and management systems, with the use of interface points on the network elements.

The TMN model describes four layers for network management:

- Business management layer: performs functions related to business aspects, analyzes trends and quality issues
- Service management layer: performs functions for the handling of services in the network: definition, administration and charging of services
- Network management layer: performs functions for distribution of network resources: configuration, control and supervision of the network
- Element management layer: contains functions for the handling of individual network elements. This includes alarm management, handling of information, backup, logging, and maintenance of hardware

At each of the four layers in the TMN model, there are defined five functional areas called FCAPS:

- Fault management: Fault recognition, isolation, reporting and recording.
- Configuration management: Installation of network equipment, setting of states and parameters, configuration of network capacity.
- Accounting management: Collection, buffering and delivery of payment and accounting information.
- Performance management: Collection, buffering and delivery of operating statistics for network optimization and capacity planning.
- Security management: Administration of authorization functions; handling of simultaneous use of an OSS, protection against intrusion from un-authorized users.

The majority of the different management systems are designed from the telecommunication vendors follows this model, though their TMN integration, the holistic approach of this model in an organization, usually is a very complex engineering project. The coordination of different teams or stakeholders, with the automatic control of different technology on machinery becomes more difficult, when dealing with large, complex projects. The handling and processing of all network information into operational workflows leads to OPEX leveraging, but is an even more complex project. Though, it is mandatory, if operators are willing to achieve excellence in (pre)provisioning, qualification, proactive maintenance and troubleshooting. The trend in technology that gives the solution to these complex projects is the use cognitive information or management systems.

Cognitive Management Systems in broadband networks

Cognitive management systems engineering is the vision, which combine the fundamentals of knowledge management, pursue high degrees of cognition, intelligence and autonomy. The cognitive approach requires to be developed in a network management perspective, throughout all organizational levels of an operator. In non-greenfield developments, where traditional management system exist, the cognitive approach is a bigger challenge, as the puzzle of re-engineering the transformation of network elements, systems, business functions etc. makes things more complex.

Cognitive management systems have been developed to provide analysis both in technical and managerial levels, to model and conduct operational, managerial and strategic processes, to fulfill automation control and governance across and organization. They are specialized for a win-win relationship of maintaining low OPEX on an operator and the delivery of higher quality of service and experience on the subscriber. Several cognitive information systems have recently being developed, mainly from telecommunication manufacturers of access equipment, that provide monitoring and modeling of the quality and stability of dsl lines, while at the same time proceed to dynamic service and spectrum management upon specific scenarios designed by the operator. These attempts are proven for their effectiveness, though they lack, as their nature is to operate strictly on the dsl central office equipment (DSLAM). The real value for a telecommunication operator is to go beyond the strict limits of the DSLAM, incorporating to the cognitive logic additional elements and management systems that may be used to increase productivity and efficiency for the operator, quality of experience and innovative services for the consumer.

Future cognitive systems are not only focused on the xDSL management, but parts of the information system interact with elements beyond the DSLAM and its management system. What has to be integrated in this framework is:

- The traditional telephony access gateways with the narrowband line test functions
- SELT
- DELT
- Performance Counters
- The management systems for xDSL and other CPEs
- The GIS systems
- The value of managing the broadband remote access servers (BRAS) and authorization – accounting – authentication (AAA) server logging options

This combined information into a cognitive approach leads to solutions that enable pro-active and efficient maintenance of broadband lines and assure the quality of the offered services. The lifecycle of such actions requires first of all identifying the copper – physical medium situation. Secondly to tune the transmission techniques based on the offered service and upon individual copper condition and spectrum management regulations. Third, is to measure the performance of the offered service and dynamically take actions, starting again from the beginning, using a cognitive approach.

The key components of such a management system are the line quality classification and the dynamic configuration management, in terms of spectrum, service and coding.

Line Quality Classification

The classification of the state in which a copper pair fits, is the group of thresholds in specific values, for a given service to be served poorly, adequate or ideal. This is the driver for the design of the functions of the cognitive system. The separation of service stability and service performance is the hint of that exercise. A line that does not resynchronize at all is considered stable. The performance of a line for a given service varies on the bit rate, the bit-error-rate, the delay, the retransmissions etc., depending on the type of service offered through it.

There are metrics ideal to qualify a line for this purpose and can be grouped in the following categories:

- Physical medium, where the measurements of Narrowband line tests and SELT/DELT are used.
- Performance data, where the dsl performance counters are used.
- End-to-end and statistics combination, where multiple statistics are combined from different network elements (BRAS / Video Servers) to reveal the line's situation.

In the physical medium group, the electrical characteristics of narrowband line test are taken into consideration. Foreign Voltage, insulating resistance and capacitive balance can be considered as performance indicators for the service classification. SELT and DELT bridge tap prediction function is also an indicator of the situation where a copper pair is, while at the same time the tap's effect can be measured.

In area of stability, three major indicators are used, exported from the dsl performance counters. The first is the mean time between errors, or MBTE. The second indicator is the mean time between retrains, or MTBR. The third indicator is the number of failed attempts of a line to resynchronize, which indicates a possible low quality line and inappropriate settings for the line.
Stability refers to the degree of connectivity of a modem and to the absence of spontaneous resynchronizations and error events from a line. Stability is measured in terms of MTBR, failed inits, and MTBR. As mentioned before, spontaneous resynchronization may happen due to errors / crosstalk, low quality lines, not proper operation of CPEs. Spontaneous is not something related to power or user behavior, as the "dying gasp" option separates these actions. The spontaneous resynchronizations are especially disruptive and undesirable in a modern services environment. A low MTBR indicates that the modem is resetting frequently and indicates that the line is unstable. Initialization failures (failed inits) occur when a modem cannot synchronize for some reason and also indicate that the line is not stable. This is actually the aggregated "showtime" of the line, divided by the spontaneous resynchronizations.

Stability measured in in terms of Mean time between error events (MTBE), is counting the error event over the synchronization time; error event or code violation of the cyclic redundancy check on the DSL physical layer. A coding violation in the xdsl transmission can indicate retransmission or packet loss in terms of network/application layer, depending on the type of traffic sent (TCP/UDP etc.).

In the statistics combination group, can be metrics coming from other network elements. Some of them are specific service related ones, while others apply to all services. The indicator of the authentication attempts on the AAA server, versus the synchronization attempts is a factor that indicates low performance on the authentication servers or load on the BRAS. A similar indicator is the accounting termination request versus the synchronization attempts, which indicate if the connection of the DSLAM with the BRAS was interrupted with service affection.

Service templates

Best practices and service requirements define the thresholds required for the classification of a service in terms of for stability, performance and quality of experience. This classification is different as per service offered, and a template of characteristics for each different type of service or product has to be defined. It is obvious that pure internet service has lower performance requirements than IPTV or voice over internet – VoIP. As a result, different metrics are collected and monitored for different Service Templates, which quantify the classification of a given service.

Internet service

A service template fitting the profile of internet usage can have the following parameters.

Service template type:	**Internet Service**
MTBR threshold stable [s]:	21600
MTBR threshold unstable [s]:	10800
MTBE threshold stable [s]:	6
MTBE threshold unstable [s]:	2
MTBE threshold stable [bits]:	100000000
MTBE threshold unstable [bits]:	5000000
Bitrate DS threshold type:	Actual vs. planned
Bitrate DS threshold:	0
Bitrate US threshold type:	Actual vs. planned
Bitrate US threshold:	0
Attempts per CPE synchronization threshold stable:	2
AAA authentications / Resynchronizations	2

Table 1: Internet Service Template

The values for the MTBR and MTBE threshold stable define the limit between the good and medium stability. Similar, the unstable thresholds define the limit between medium and poor stability. A line used for dsl only, may not be so problematic in terms of retransmissions, as the internet usage is mainly TCP based, those retransmissions is part of a “normal” behavior. What has to be taken into consideration is the spreading of these errors through the time. If less than one packet every 100mbps is lost, or less often that 6 seconds, the line is considered stable.

If a line resynchronizes less frequent that 1 time every 6 hours (21600 seconds) the line is considered stable. If the line is not stable and is resynchronizing less frequent that 1 time every 3 hours (10800 seconds) the line stability is considered medium, otherwise the line is unstable.

More than 2 attempts for the CPE to synchronize after a line cut or a power restart of the CPE indicate that the line stability is not so good and the availability of the service is lower than expected.

The value of authentication attempts divided by resynchronizations, present the performance of the service availability on the subscriber. If more the authentication attempts are double than the retrains, this indicates a possible malfunction on the AAA or BRAS.

Last, if the actual synchronization rate is lower than the planned one in the adsl profile, this means that the line will behave better if in a lower profile.

Data transfer

Regarding services whose nature is sensitive of fast, non-real time data transfer, specific service profiles may target them. A service template for this category follows.

Service template type:	**Data transfer**
MTBR threshold stable [s]:	28800
MTBR threshold unstable [s]:	14400
MTBE threshold stable [s]:	6
MTBE threshold unstable [s]:	2
MTBE threshold stable [bits]:	100000000
MTBE threshold unstable [bits]:	5000000
Attempts per CPE synchronization threshold stable:	2
AAA authentications / Resynchronizations	2
TCP Maximum Window Size	65536
Maximum Segment Size:	1460
Delayed Acks:	Yes
Roundtrip Backbone:	20
Initial Window Size:	4
File Size:	1.0E9
Backbone Packet Loss [%]: *	2
Throughput classification threshold high (kbits/sec):	1,5*planned bit rate
Throughput classification threshold medium (kbits/sec):	0,9* planned bit rate

Table 2: Data Transfer Service Template

The MTBR and MTBE values for this type of service follow similar stability thresholds like the internet service usage. Same values can be considered for the CPE attempts of synchronization and the AAA authentication / resynchronizations.

What is important for the performance of this service is the throughput ability of the CPE, to download as it should. In this point, a testing mechanism can be adopted and initiated on a campaign basis, during low traffic hours, or on demand, via the Auto Configuration Server and the TR-069 protocol. Throughput tests can be simulated with an FTP download from the CPE up to a specific FTP server.

The parameters that affect throughput are the TCP Maximum Window size, the Maximum Segment Size, the possibility to use duplicate or delayed acknowledgements, the initial window size and the round trip time, from the CPE up to the FTP server.

The test may take as optional parameters possible known issues in the backbone that create a measured packet loss and may run until a specific amount of data is transferred, controlled by the size of the downloaded file.

Depending on the planned bit rate posed by the adsl profile, throughput results may qualify as good, medium or poor in terms of performance. Furthermore, additional information can be extracted that indicate:

- The copper condition
- The appropriate xdsl settings regarding noise protection schemes and retransmissions
- The appropriate configuration settings of the CPE
- The backbone delay imposed

Online Gaming

A specific profile of users enjoys the multi-player online games. This type of service is not so critical in terms of stability, though it is critical that the latency of the CPE up to known servers hosting these games to be the minimum.

Service template type:	**Gaming**
MTBR threshold stable [s]:	21600
MTBR threshold unstable [s]:	10800
MTBE threshold stable [s]:	6
MTBE threshold unstable [s]:	2
MTBE threshold stable [bits]:	100000000
MTBE threshold unstable [bits]:	5000000
ICMP Payload Size [byte]:	40
Max. Total Delay [ms]: *	250

Table 3: Gaming Service Template

Another test set that can target specifically services like on-line gaming is ICMP tests towards the known gaming servers. This test also can be executed from the TR-069 platform.

Latency may be imposed due to different causes, other than the dslam. For this reason, this test is performed towards all active network equipment, consisting the path to the servers.

Depending on the payload size of the ICMP packet and the calculated delay imposed by the dslam or the aggregation network, the result of the total round trip time may indicate:

- Inappropriate xdsl settings regarding delay
- Aggregation delays
- Backbone delays
- Poor server performance
- Poor CPE performance

Again upon defined settings, the classification of a line may be good, medium or poor, if the problem is related on the access network (copper – CPE- dslam), or a relative alarm can be triggered to indicate a backhauling problem (aggregation – backbone – server performance).

IPTV

The IPTV type of service is probably the most demanding one in terms of stability and errors.

Service template type:	**IPTV**
MTBR threshold stable [s]:	43200
MTBR threshold unstable [s]:	28800
MTBE threshold stable [s]:	600
MTBE threshold unstable [s]:	360
MTBE threshold stable [bits]:	800000000
MTBE threshold unstable [bits]:	10000000
Video Codec:	mgeg2
Video Resolution:	Sd
Bitrate (> of kbps):	5000
M Frames between I-frames:	12
N Frames between I- or P-frames :	3
Payload Size:	1460
Visual artifacts classification threshold high (#/hour):	2
Visual artifacts classification threshold medium (#/hour):	10

Table 4: IPTV Service Template

MTBR for stable lines must be higher than 12 hours, while the threshold for a medium stability is the 8 hours.

In IPTV, the synchronization bit rate plays a very important role: the actual bit rate must be higher that the bit rate of the broadcasted video. Special care must be taken on the dsl profiles. The classification can take into consideration the video codec (h264, mpeg2, mpeg4 etc.) and the video resolution (standard definition – high definition) are parameters that quantify the required bit rate.

Furthermore an MPEG stream may contain different frames:
I-frames: Intracoded frames (self-contained JPEG-encoded pictures)
P-frames: Predictive frames (block-by-block difference with last frame)
B-frames: Bi-directional frames (differences with last and next frame)

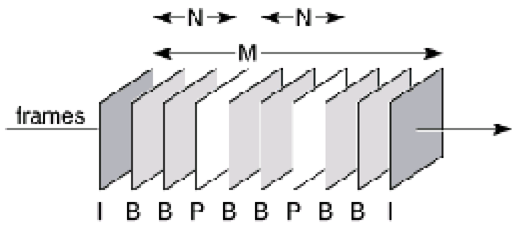


Figure 7: MPEG I,P,B frames

The related metric for offered quality of experience in IPTV users, can be the M Frames between I-frames and the N Frames between the I-frames and/or P-frames. This can be related to MTBE, as it represents at the application layer the effects of errored frames. In other words, the visual disturbances may be monitored as the mean time between visual artifacts that indicate the video service classification.

VOIP

Similar for VoIP specific services, what also is important is the VoIP codec used, the packetization delay and the echo loss.

Service template type:	**VoIP**
MTBR threshold stable [s]:	43200
MTBR threshold unstable [s]:	28800
MTBE threshold stable [s]:	4
MTBE threshold unstable [s]:	1
MTBE threshold stable [bits]:	200000000
MTBE threshold unstable [bits]:	10000000
Attempts per CPE synchronization threshold stable:	1,5
VoIP Codec:	g711, g729
Packetization Delay [ms]:	20
Echo Loss [dB]:	50

Table 5: VoIP Service Template

The stability of the line must be similar to IPTV type of service, with increased MTBE and MTBR

Dynamic Service Coding and Spectrum Configuration Management

Line quality is a factor of line stability and performance. As described above a line is either stable or is not based on thresholds MTBR, MTBE, failed inits etc. Performance, consists of factors that are maximized (bit rate) or minimized (latency, power use) etc. Taking into consideration that the stability or service quality of a line may be degraded through time, due to various reasons, several configuration corrective actions can be applied in order to tackle the unwanted possible behavior. The continuous adaptation of the settings through time can be achieved through Dynamic Rate Management, Dynamic Code Management and Dynamic Spectrum Management. These three functions in the cognitive management systems are generally described as Dynamic Line Management or DLM.

DLM is ideal to overcome and balance with all aspects of a line's performance and stability:

- As described in dsl transmission techniques, the higher the synchronization rate, the lower the SNR on a given line, which can lead to higher MTBR and MTBE.

- Error correction techniques impose latency on the data transmission. In specific type of services, this latency is not important and possibly not noticed by the end users. In others, like online gaming, high delay values decreases the quality of experience. In IPTV usage, the higher the latency and the Impulse Noise Protection (INP), the better. Though, the higher the INP, the lower the dsl synchronization rate.

- Maintaining the aggregate transmit power to low levels, crosstalk between adjustment lines is minimized, the overall line performance is better and power consumption is low. Though this power level, if not set correctly, can be devastating for the service stability. Similar is the fine tuning of the VDSL lines, in order to follow regulation demands and not to distort the ADSL2+ lines.

Target of DLM is to maximize the stability and performance of a line, applying the appropriate settings, minimizing the waterbed effect between line rate, maximum latency, Impulse Noise Protection (INP) and transmit power, until thresholds for the offered service are met.

DLM Strategy

The way the DLM realizes to which settings a line must be imposed, is defined in the DLM strategy. In the DLM strategy, several different configuration sets are created. As the requirements of the DLM function is on 3 fields (rate, coding, spectrum), the strategy of DLM has to follow 3 axis. In each axis position, set of settings are applied to a line that formulate its configuration.

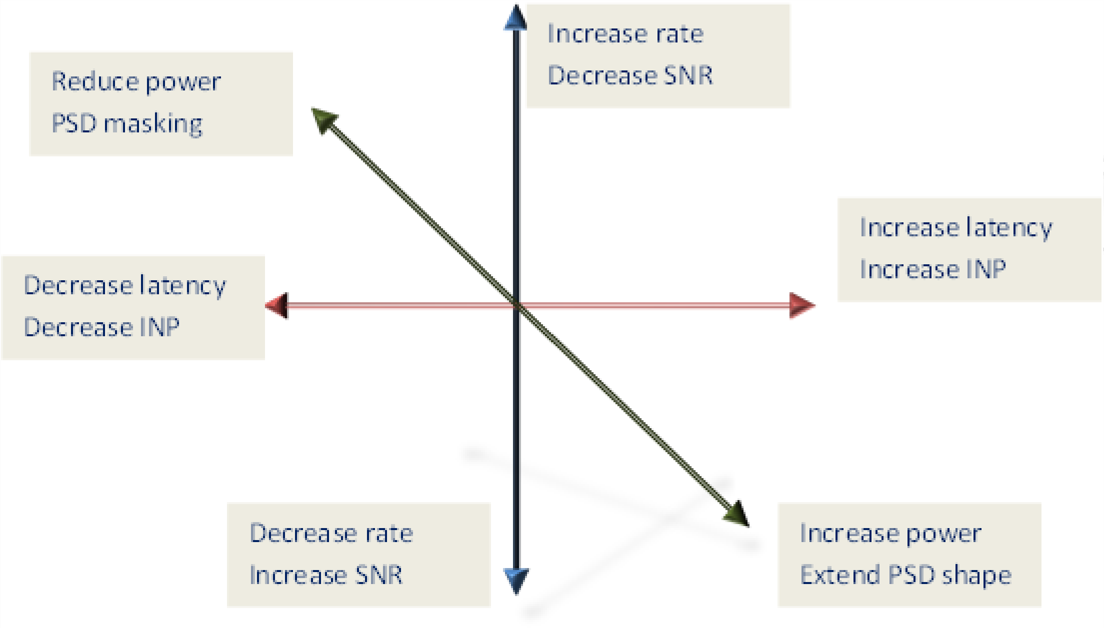


Figure 8: 3-axis DLM Strategy

The design of the profiles in DLM has some constrains that have to be taken into consideration. First of all is the regulation sector. The local authorities impose rules either to strengthen the competition or to define the smooth operation without interference between the different operators, or both. These constrains usually have to do with the power spectral density of the transmitted signal.

The different types of services require different parameters to be defined. The constrains of each service have to be met when designing the DLM. . For instance, in IPTV type of service, the coding parameters of the profiles used, cannot have Impulse noise protection lower than one symbol and delay less than 8 msec. accordingly, such profiles are not at all suitable for online gaming purposes.

Among with the regulation and type of service constrains, each operator may add others, that are customized for each network needs. Taking into account all the constrains, the DLM strategy is formulated. The DLM strategy is set of settings in profiles, with rules for transition steps. Transition is happening once some parameters have exceeded some thresholds and a corrective action has to be performed, in order to meet the different constrains and maintain the desired quality of experience for the subscribers. Transition is controlled by an algorithm that meets the above mentioned criteria.

The differentiation on the profiles is defined in discrete steps, in order DLM strategy to have an easier algorithm to apply. That means that moving for example in the horizontal axis, the only different in the possible profiles is the latency and the INP protection, in discrete steps. These steps may not have equal distribution, though a linear change must happen. When DLM algorithm decides to change a profile, a transition is done. Transitions between profiles may be done in more than one step. For instance, assuming that a line is initially configured in the

24mbps profile and during the data collection period, the line's attainable rate was 8mbps. If the step on the line rate was every 4mbps, DLM would decide the transition to the 8 mbps profile and not the 20 – 16- or 12mbps.

The existence of GIS systems in this approach is a guidance of the possible attainable rate, common spectrum and profile settings that lines in the same geographical area may achieve. This way, DLM is targeting to reach closer firstly to the average values of the area and then try to overcome these.

DLM lifecycle

In DLM there are different phases that separate the status of the procedure. Among with the procedure phases, lines are also changing roles on the DLM status.

The first thing needed in the cognitive approach is an automated process that collects all performance and diagnostics data generated by the DSLAM, the BRAS, the GIS system, the AAA, the test applications, the TR-69 and all other involved parties.

If the line imposed for DLM is new, there are no data collected for such purpose. In this case, DLM takes into consideration the average values of all collected data in lines that are geographically located in short distance like 100 meters radius from the subscriber premises, with the use of the GIS system.

Once data is collected, then it is analyzed and each port behavior is classified based on stability and performance. This part consists the analysis phase of DLM. All lines monitored by the cognitive system are initially in a DLM operational state. The first thing DLM tries to improve is the stability of the line and performance comes next. The average classification values exported by the GIS, is the target to overcome. This way in a semi aggressive mode, all lines are tuned to overcome the possible configuration limits.

According to the service template a line is assigned, specific thresholds have to be met. DLM algorithm determines whether a configuration change can improve the behavior of the line. The improvement can be achieved upon transitions on the DLM strategy.

Depending on the measured line conditions, an automated process may choose the optimal configuration profile settings for the specified offered service. This selection is made moving in the three axis of rate-coding-spectrum. This deterministic function of DLM can be considered that is included in an analysis phase. If for a line a transition is needed, this line is getting out of the DLM operational phase and enters at the state of switching execution.

As the execution of the profile change in the dslam creates service interruption, specific time windows are configured to enable these transitions from the system. Once the switching is done, the result need to be evaluated. Lines are entering the evaluation state, waiting for the validation phase of DLM to finish. In validation phase like the analysis phase, data is collected, but this time is used to judge whether the transition did improve the line behavior upon the thresholds required. If so, the line is getting out of the evaluation state, entering again in DLM operation state and the validation phase moves ends.

If not, that means that the corrective action either did not improve at all the behavior, or improved but not adequately. In the first case, the line profile rolls back to the previous one and a different axis is chosen as the next transition. If again there was no improvement, the settings are again rolling back and the third axis is chosen for a new transition. If improvement is made, the previous profile is marked as inappropriate and the line goes in operational state. If still no improvement is made, the line state switched to ineffective and DLM function ends for it, waiting the administrator of the DLM strategy to improve it. In the second case, the line is entering the switching execution state, applying the next closest transition profile towards the improvement needed.

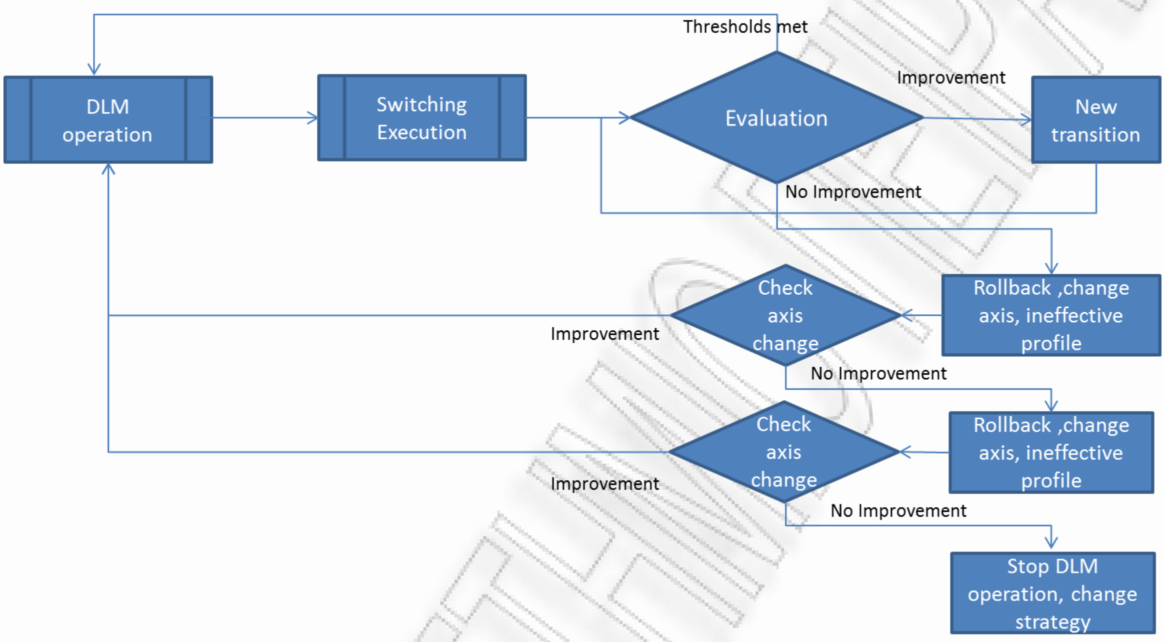


Figure 9: DLM Strategy workflow

If specific profile settings are not suitable for a line's behavior, the system marks these profiles and does not apply them for the same line for a given period of time. If no profile transitions are can improve a line's behavior, the line is the ineffective state.

Interface requirements

A system like the one described has a core role in the structure of the systems and network architecture on an operator. It can be used as a broadband service support system, incorporating actions for service assurance, provisioning, engineering and planning. The CMS may directly communicate with the network elements or use the relevant element managers that handle the requests coming from the CMS to the nodes. Thus, we may figure the following diagram about the position of the CMS on the network.

The interaction with higher levels of OSS/BSS, can be done with relevant communication protocols that are standardized for such use on northbound interfaces. It can be considered that the cognitive system acts as a middleware towards the upper functions of an organization, so the relevant communication must be flexible:

- In case the use of Web Services is a must, SOAP can be the communication protocol, which is versatile enough to allow for the use of different transport protocols.
- In case the communication as middleware is considered slow, CORBA is the most appropriate protocol, which provides better performance compared to SOAP.

Element managers act as command concentrators towards network elements, providing also technology transparency between the cognitive systems and the network. In case the network elements do not exist, or cannot be used, cognitive systems must be flexible enough to directly communicate with the relevant elements. The communication with the element managers can be done either by SOAP, or by CORBA, while the communication with the network elements can be TL1 or SNMP.

Part III: Case study

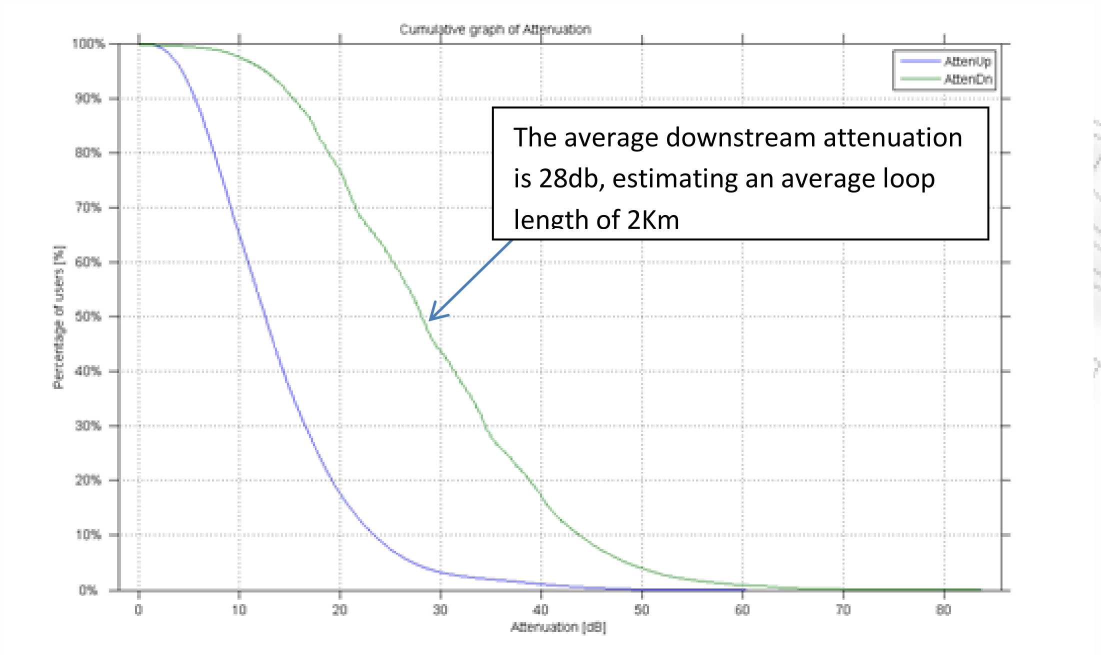
An attempt to integrate a future proof cognitive management system in the workflows of engineering and operations in a European telecommunications operator as case study is analyzed in this part of the thesis. The scope was to implement the architecture of such a system and measure the benefits after this integration. The DSLAMs used by the operator were Alcatel Lucent ISAMs 7302 and Ericsson's series EDA 2530. The BRAS used was Juniper E320 series, the AAA was Juniper's Steel Belted Radius. GIS geocoding was implemented in Google maps. Alcatel Lucent product 5530 Network Analyzer was used to collect data from the relevant DSLAMs. The workflows of line quality classification and a mediation platform to handle communication issues were integrated in operator's server equipment. The operator was offering voice and internet services, while evaluating VDSL access and IPTV/VoD (Video on Demand) services.

Initial network benchmark

In order to conclude to safe results, a benchmark was held in order to monitor the situation of the network before the platform proceeded to DLM. For this reason, metrics that were used on service templates and having to do with the access network were under analysis.

Attenuation distribution

The first interesting thing was to calculate the average loop length. This was done assuming that for almost every 13,81db of attenuation downstream, the loop length is 1Km.



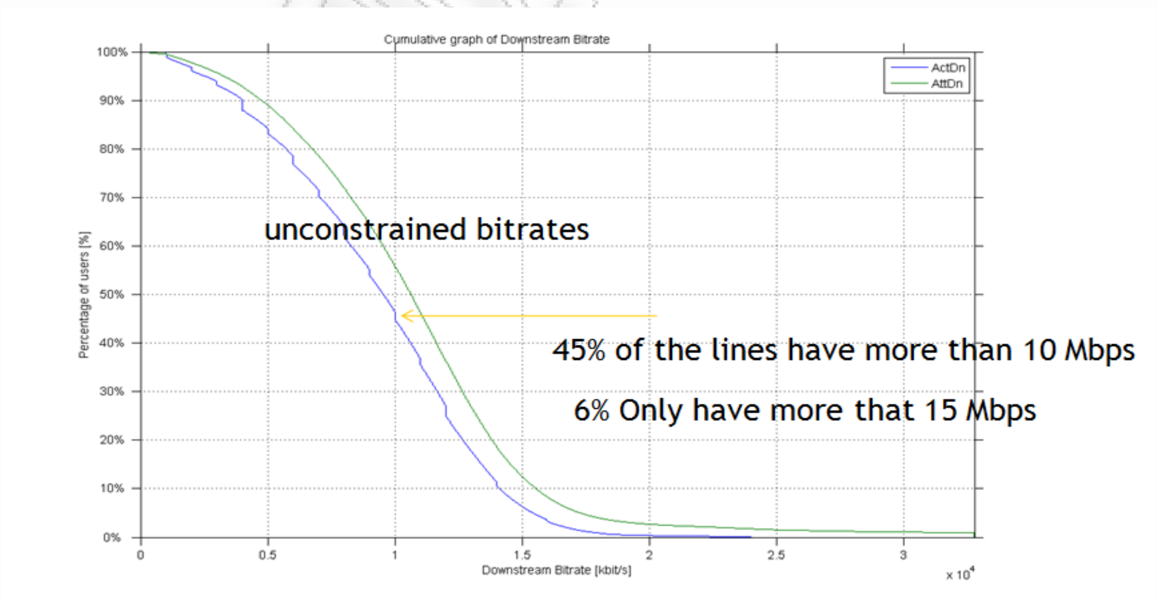
The average downstream attenuation is 28db, estimating an average loop length of 2Km

Figure 10: Attenuation cumulative graph

The results presented an average loop length of 2km or 28db attenuation. Upon DSL theory, for this attenuation in a noise free environement, the average line rate should be expected arroung 16mbps.

Bit rates downstream

The average actual bit rate was really lower. Only 45% of the lines could achive more than 10mbps and only 6% more than 15mbps.



unconstrained bitrates

45% of the lines have more than 10 Mbps

6% Only have more that 15 Mbps

Figure 11: Bit rates cumulative graph

The fact that actual and attainable bit rate were presented close one to the other, means that the maximum bit rate of the profiles used was not the root cause of this low performance. Unconstrained bit rates were defined in the profiles.

Noise margin

The target noise margin in the profiles was visible to be at 9db. A percentage of these (10%) had more that 12db, indicating that the action of the troubleshooting followed so far for problematic lines was the increasing of target SRN or the lowering of the bit rate.

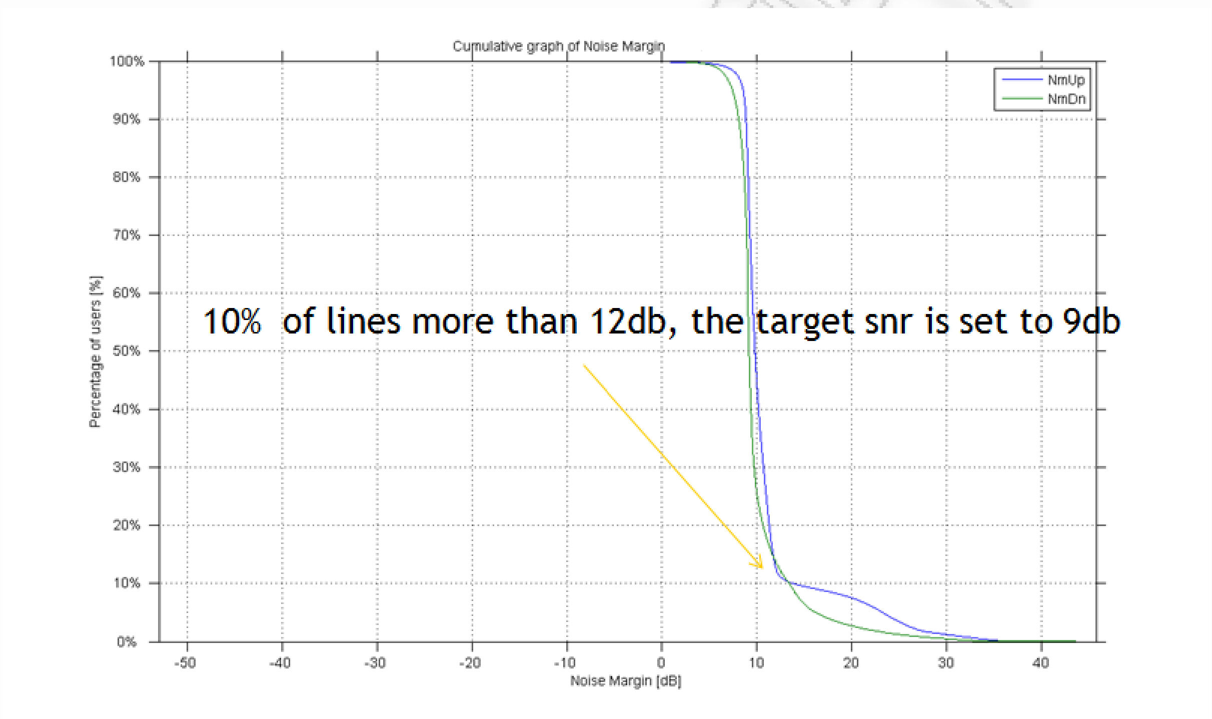


Figure 12: Noise Margin cumulative graph

Showtime

The average showtime had to be measured, in order to predict the user behavior. Powering off the CPE can be a user action. Network disconnections can be an unpredicted situation. Both these two issues affect the showtime counter. It was calculated that in and 24h period, the 60% of the CPEs were always syncrhonized.

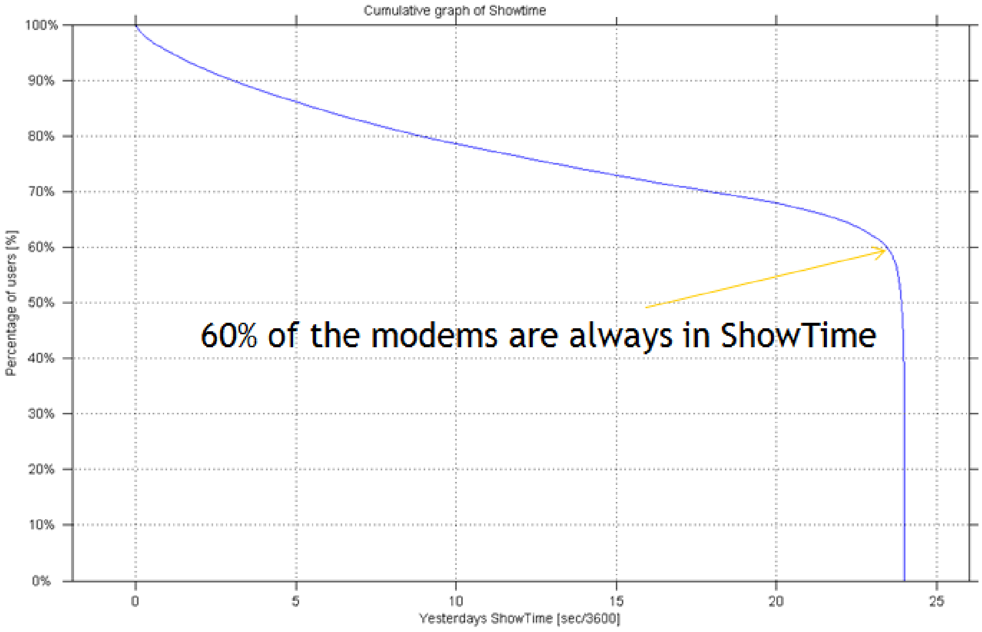


Figure 13: Showtime cumulative graph

MTBE - Stability

Perfrormance of the network was benchmarked as it has been mentioned above in the service templates. The mean time between errors for IPTV lower than 360 seconds or 6 minutes would indicate a bad service; the same value for internet service was 2 seconds.

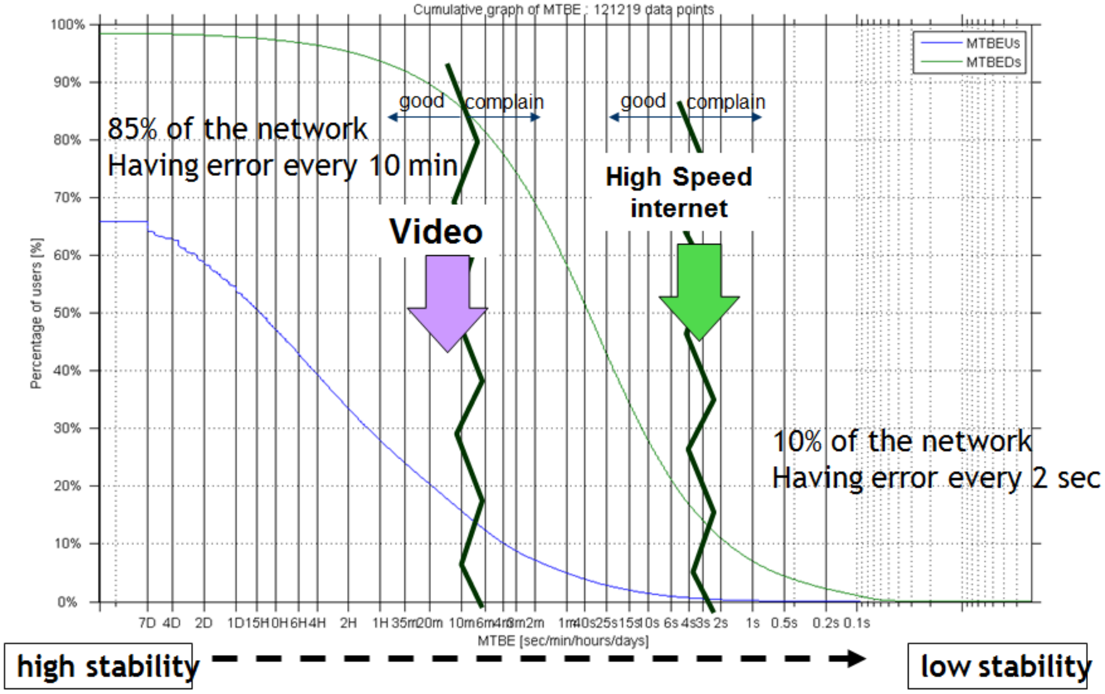


Figure 14: MTBE cumulative graph

The network did not perform well. Only 15% of all the lines could perform well in an IPTV scenario. Furthermore, the 10% of the lines was performing badly even in Internet service.

The aggregated network stability, for all types of service, generated the below pie. What was taken into consideration was the MTBE in bits, the MTBR, the actual line rate and other constrains and statistics formulating the following report. The meaning of the report is the prequalification of a line to serve adequately the give type of service.

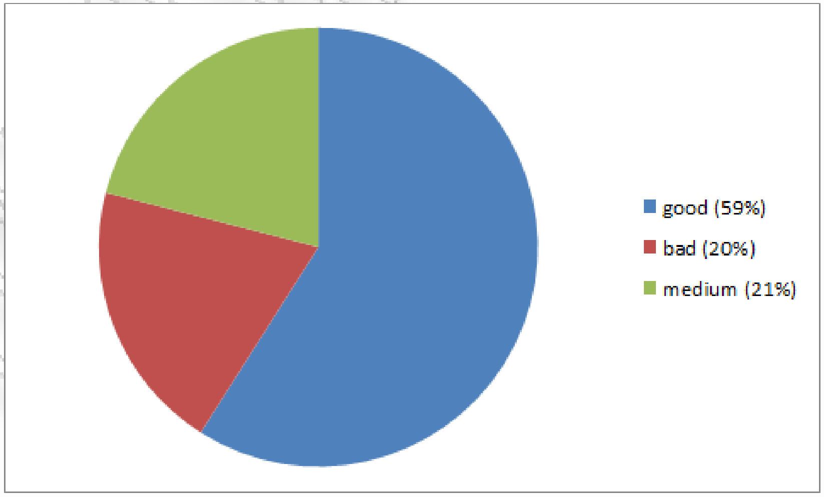


Figure 15: Overall initial stability graph

DLM benchmark – Cognitive approach

A part of the network was initially selected to operate with the cognitive management approach. The DLM function was applied to 7000 lines, as a subset of the total network, including highly dense urban local exchanges, suburban and villages exchanges. The benchmark of the network results were used to formulate an even better DLM strategy and profile settings selection for the DLM transitions.

DLM algorithm automatically configured lines to ensure high line performance and stability. The ideal configuration for internet service, depending on the measured line conditions was applied. If in specific lines the service could not be improved, relevant alarms were generated for the customer care to act proactively on subscribers. For every problematic line that was requesting an agent’s action, inspections were executed by the system and reports were generated, in order persons not to lose time troubleshooting.

In this framework, settings were adjusted automatically, while service interruptions were minimized. DLM period was counted for 3 months.

The results and schemes below refer snapshots of the network before and after the DLM introduction, considering stability and performance.

Internet service template - Stability

The stability figures of the internet service profile were counted before and after the DLM on the subset of lines selected. Lines with good stability improved from 62% to 85%. Lines with medium stability changed from 21% to 9%, while the unstable lines were minimized from 17% to 6%.

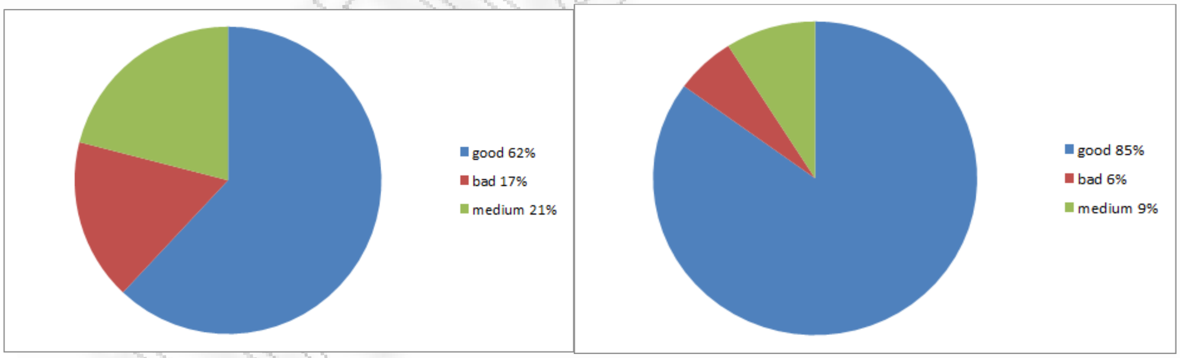


Figure 16: Stability graph before and after DLM

The figure below represents the stability evolution in time. The first bar in the graph represent the situation before DLM, while the 3 next bars represent the evolution through time weeks.

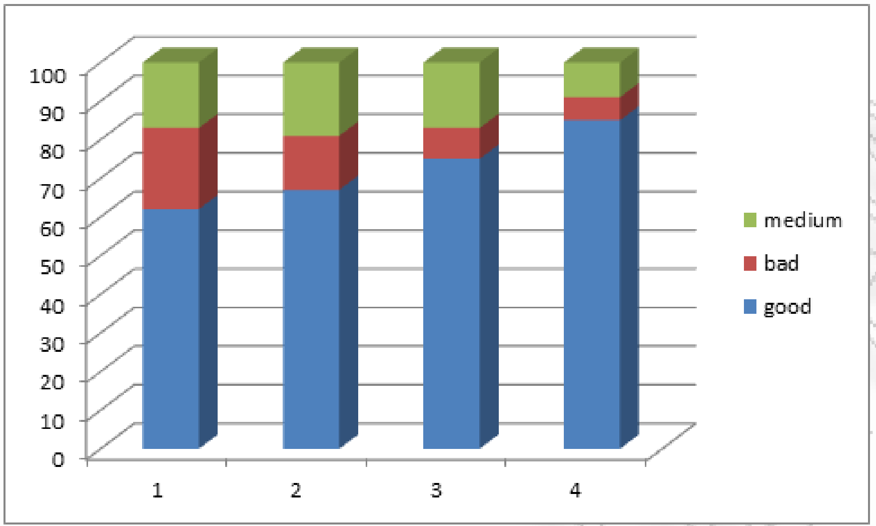


Figure 17: DLM weekly stability evolution graph

As appeated from the graph, the DLM startegy first handled the bad lines, whose actions were immediatelly proven, as the medium stability lines improved. In later phases, the medium stability were tuned to be stable.

MTBE

The improvement on MTBE declared possitive results. Acconrding to the internet service template for MTBE, where the values of 2 sec and 6 sec are the threshold to medium and good, a noticable improvement was obvious:

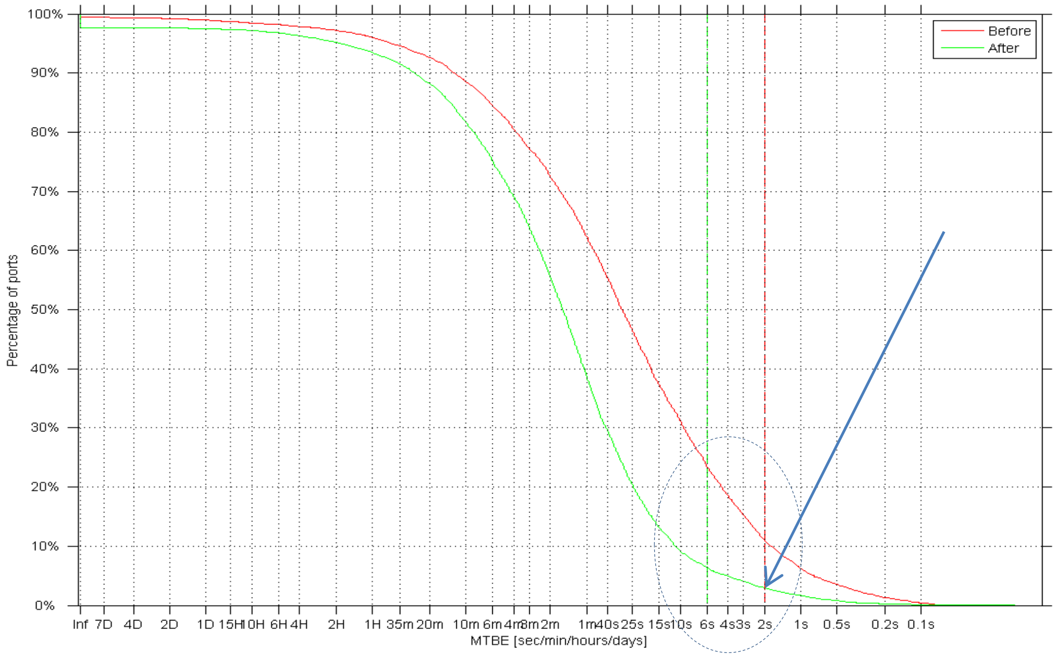


Figure 18: DLM - MTBE comparison graph

The 10% of lines scoring bad in MTBE were reduced to 3%, while the relevant medium from 23% to 7%.

Filtering the lines with MTBE value greater than 2 seconds the below report was generated for the relevant lines in DLM benchmark.

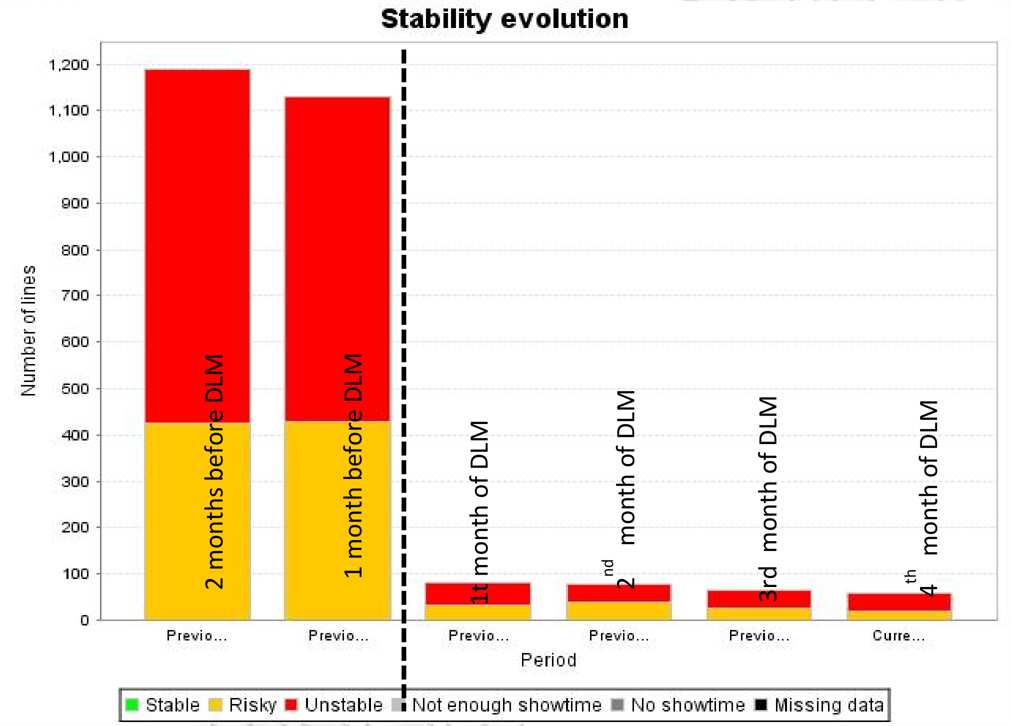


Figure 19: Stability evolution for MTBE

DLM maintatined the number of lines with not good MTBE level as low as possible.

MTBR

The MTBR evolution is similar. For the given part of the network, before DLM 40% of the lines did never resynchronize. After DLM 60% did not resynchronize at all. The thresholds for the stability profile in Internet service for 3 and 6 hours were observed in the diagram below.

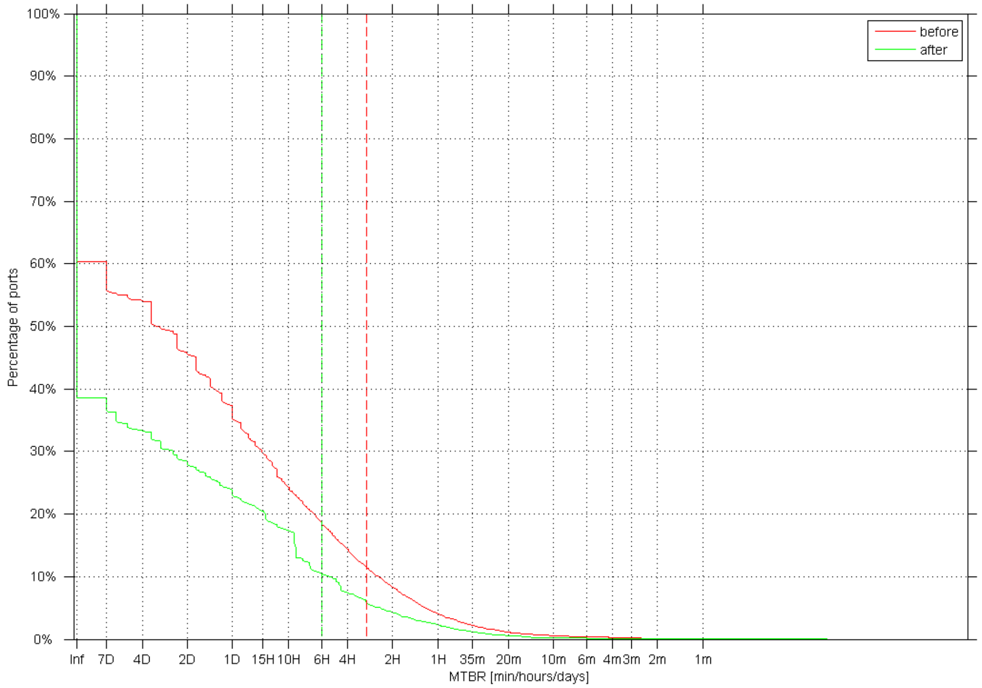


Figure 20: DLM - MTBR comparison graph

The stable lines in MTBR were increased from 80% to 90%. Medium stability went form 12% to 6%. Last the bad stability lines were reduced from 8% to 4%.

Filtering the lines with MTBR value greater than 6 hours the below report was generated for the lines in DLM benchmark.

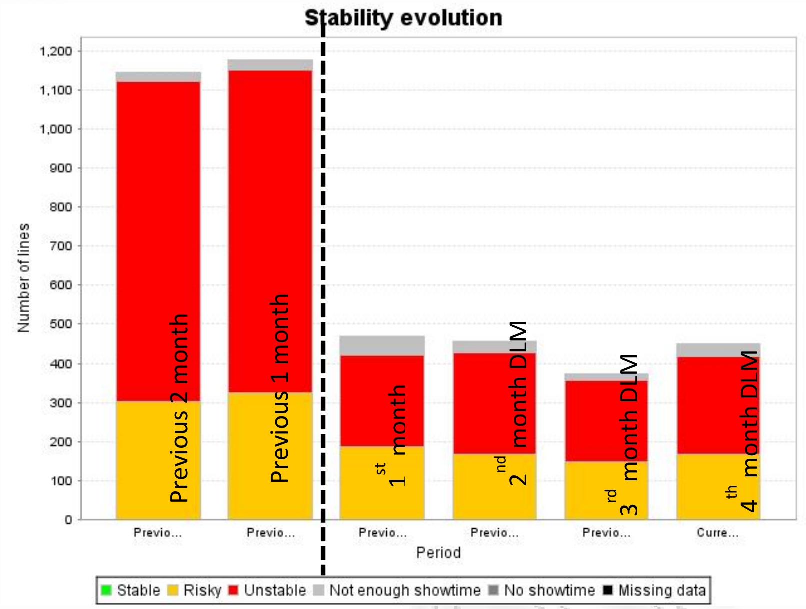


Figure 21: Stability evolution for MTBR

As a result of the MTBE improvement, the MTBR improved as well.

Bit rate comparison

A comparison of the bit rate on these lines before and after DLM was performed. The result indicated a 12% bit rate increase in the aggregated data rate. What was noticeable also was that the bit rates on some short lines was reduced in order the lines to ensure stability, while on the medium to long loop lengths the rates were increased, as a result of applying the appropriate profiles for each line.

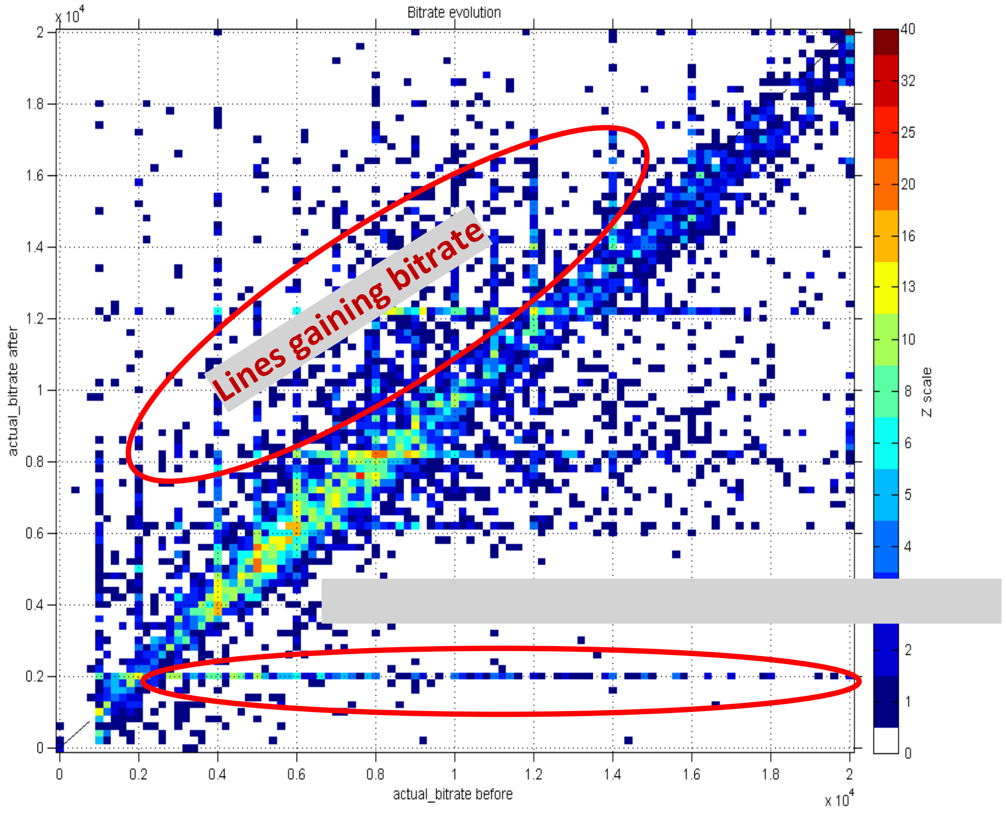


Figure 22: Bitrate evolution

There were lines that gained or loose bit rate from the DLM. Lines with long loops and physical problems that could not be improved, were configured to be in the lowest DLM strategy profile of 2 Mbps (0,2* 10^4). The different steps of profiles can be seen in the graph as horizontal lines with high concentration of points.

Efficient and proactive troubleshooting in cognitive copper assurance

As presented above, the benchmark results on the operator's network were indicating a really bad performance and quality of experience for the offered services. In order to identify with a prompt, low cost, intelligent way, for actions that had to be taken to tackle that performance, the implementation of all the mentioned troubleshooting mechanisms in a cognitive approach was the toolbox used.

Up to that point, every line was handled independently and so was every customer complain. Furthermore, whatever action was responsive. With the integration of all these tools in the cognitive network assurance platform, the operator could act proactively on many of the problems. The following issues were easily identified and handled:

Missing splitters

When a splitter is missing or damaged and the service of telephony is used, once the human action triggers the off-hook (in other words the user picks up the phone) the noise margin upstream of the synchronization goes suddenly to zero and the line resynchronizes. Before the system implementation the problem was treated retroactively upon customer complains. If the 1st level of support could figure out this root cause, the time till the problem resolution was quite prompt, around 10 minutes. In case the subscriber was not at home, or did not cooperate easily to troubleshooting driven by the support agents, or the 1st level of support could not identify the issue, the problem was escalated to truck rolls in order to ensure the resolution. These actions could take a lot of time to be handled from the 2nd level of support. With the benefits of the cognitive system, the missing splitter is proactively identified and presented on the 1st customer care user interface. The problem identification time is 2 minutes in the responsive way, while the operator has the ability to call the subscriber to resolve the case, keeping him happy for the service he has, while reducing possible churn from such issues. Totally in the network, 3% of the lines were affected by this problem and were in a very cost effective way minimized.

Excessive (varying) crosstalk

A part of the lines that appeared low performance indicators than the ones of the stability threshold in MTBR had the problem of excessive crosstalk. There was more noise on the line than the adsl profile could sustain and the lines were resynchronizing. The operator's customer care actions in order to stabilize the lines were to increase the Target Noise Margin form 9db to 12 or 15dB. The drawback was obvious: when the modem was synchronizing at a moment in time where the crosstalk was high already, it would take a huge noise margin on top and would reduce the bit rate significantly. At the same time, the crosstalk of a line with a higher power level was influencing the ones close to it.

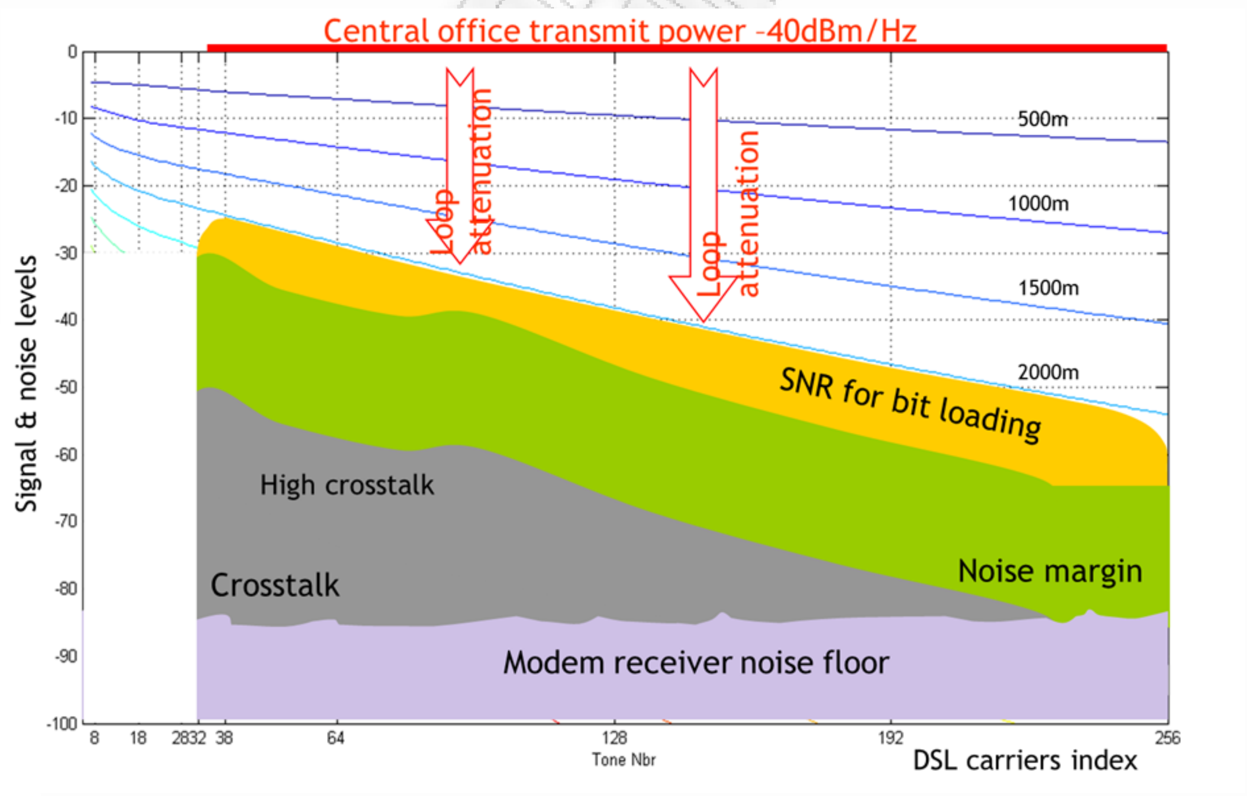


Figure 23: Crosstalk and noise margin

When the modems synchronized in low crosstalk with a huge noise margin on top of the high crosstalk, there was almost no SNR left for bit loading. This nonproductive action was devastating the network bit rates, with unpredictable results in the stability.

As already mentioned, the actual root cause of the resynchronization was not the varying low snr, but the coding violations (CVs) due to them. If the dslam profile could protect the line form the coding violations, then the stability would be for sure higher and the rates would also be better. The mechanism that counts the CVs is the MTBE; the profile configuration that helps on this situation is the interleaving depth and the impulse noise protection. The complexity of the profile settings, is that the higher the INP, the lower the rate. The higher the latency, the lower the user experience in some applications.

-	**INP_ min**	**0**	**½**	**1**	**2**	**4**	**8**	**16**
delay _max [ms]	**1**	24432	0	0	0	0	0	0
	2	24432	7104	3008	960	0	0	0
	4	24432	15232	7104	3008	960	0	0
	8	24432	22896	15232	7104	3008	960	0
	16	24432	22896	15232	7552	3520	1472	448
	32	24432	22896	15232	7552	3712	1728	704
	64	24432	22896	15232	7552	3712	1728	704

Table 6: Impulse and delay vs rates

In the responsive troubleshooting mode, the operator could count with DELT for a short period of time the CVs, but in the most of the times the prediction was not appropriate. The problems were not solved, as either the DELT results did not indicate correctly the line condition, or the customer support could not evaluate what actions should program. The customer was issuing on an average 3 trouble tickets for the same problem until the resolution, which on average was counted in 10 days. Many times extensive and expensive truck rolls were improperly issued in order to identify possible copper faults, causing long service affection, not needed operations to be held. Counted on churn, this was the main root cause that was due to service problems.

With the introduction of the platform, the MTBE was collected for every line, and batch profile changes were programmed by the operator as defined by the DLM strategy, in order to tackle quickly and instantly the low network stability. A workflow was introduced, highlighting the next appropriate cost effective action that should be taken. The resolution improved to 3 days, while the number of customer complains for the same issue was on half (1,5). The useless truck rolls for these issues were limited to 20%.

Copper and wiring faults

The benchmark indicated that 12% of the lines had problems with the wiring: connector oxidations, unbalanced loops, degraded contacts, bridge taps. All these problems affected more or less severe, both voice and data services.

The operator used to have 2 separate teams to handle customer complains. One team was handling the voice quality problems and the second the data quality issues. These teams were using different procedures and tools in their troubleshooting workflow. The voice team was troubleshooting with narrowband line test, while the other team with DELT and SELT.

In this category of problem, the operational expenses were huge. The identification of a copper fault is a difficult task, if not appropriate methods are followed. The localization of the fault is even more difficult: the fault could be in customer premises, in the copper network or the local exchange. The expensive truck rolls were counted as 3 per line problem, the resolution lasted 1 week and the customer repetitive complaints were 2 per problem.

With the introduction of troubleshooting copper using GIS, SELT, NBLT and DELT at the same time, every troubleshooting team performed better. Based on predefined thresholds on every type of inspection of these tools, a fault categorization indication was exported. The type of fault and the possible location was highlighted. An intelligent workflow was proposing the next appropriate action the agent should perform.

As a result, the truck rolls were more targeted, counted on 1,5 per issue. The resolution time was also limited to 3 days. The customers did not complain more than 1 time for the same problem.

CPEs abnormal behavior

With the introduction of TR-069 and the relative tests servers, a specific brand and type of CPEs that was offered from the operator in the past, was proven not to work sufficiently in highly noisy environments. The CPE had been used by the 10% of the subscribers and the problem was appearing spontaneously. The problem was highlighted with the parallel contribution of TR-069 and DELT figures. Finally, the CPE vendor generated the bug fix and via the ACS server the CPEs were upgraded. The operator did found the root cause of the problem, did not have to replace a huge number of CPEs that is CAPEX consuming and solved massively this issue.

A specific category of CPEs that the subscribers were using, also was not behaving as expected. These CPEs were marked as blacklisted and the customer care agents could identify directly their use. In the proactive framework, the subscribers using them were informed to replace them.

The operator was also able with some friendly users to identify if a new CPE was behaving correctly before introducing it massively to the subscribers.

RFI bands and VDSL crosstalk

In several areas where radio amateurs and AM radio stations were transmitting, the interference with the dsl spectrum was highlighted.

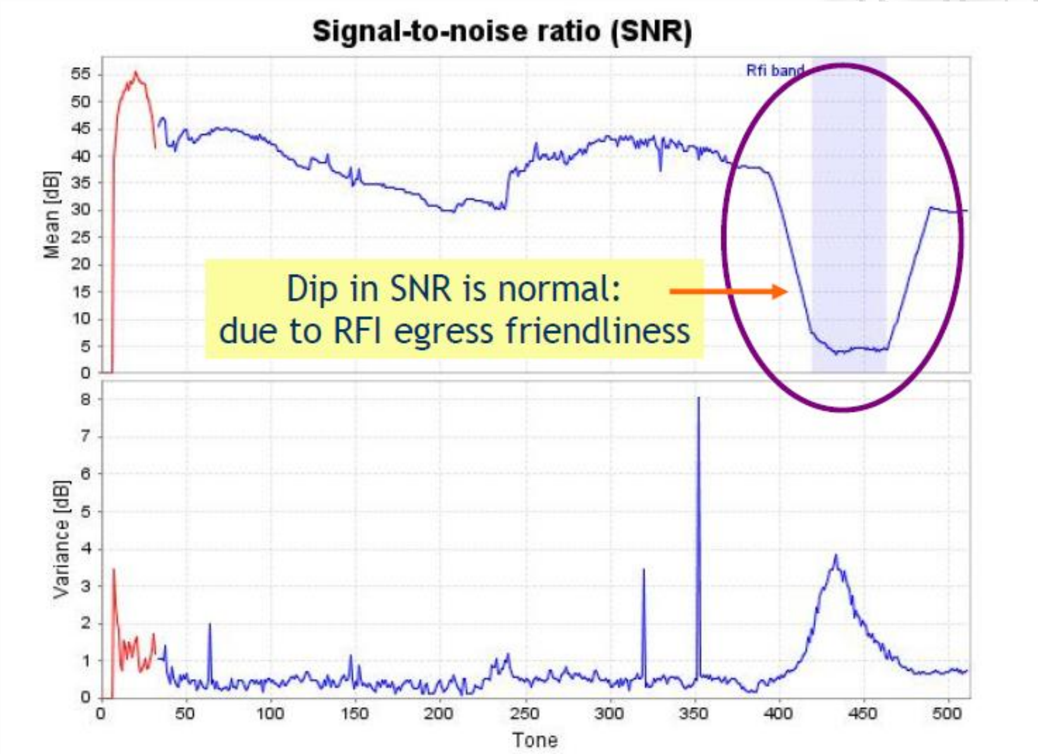


Figure 24: SNR and RFI bands

Relevant settings on the PSD were applied, with RFI notching, limiting the impact of CVs. Once RFI interference was identified, with the use of GIS tool, all adjustment lines were configured with the tailored PSD settings.

The incumbent operator started constructing VDSL network, emitting from street cabinets. The regulation authority was not ready for that. The incumbent was not taking any measures to protect the already existing ADSL subscribers of the local exchange.

With QLN measurements the problems were identified and with the use of GIS, were grouped into areas that the incumbent was destroying the service. The relevant information was handled by the operator to prove to the regulation authority the degraded network performance to issue regulation aspects for that.

Reduced power – Green DSL

Power optimization is proven to benefit the network stability, increasing bitrates, and reducing energy consumption by an operator. The way to count the effect of reducing power is a difficult exercise, as several operators share the same binder of cables.

In general, the idea is to reduce the transmit power on stable lines with excess margin, such as very short loops, or loops that do not need to perform near their capacity. This way, the unnecessary crosstalk is reduced, which in turn improves the rate/reach performance and stability of nearby lines.

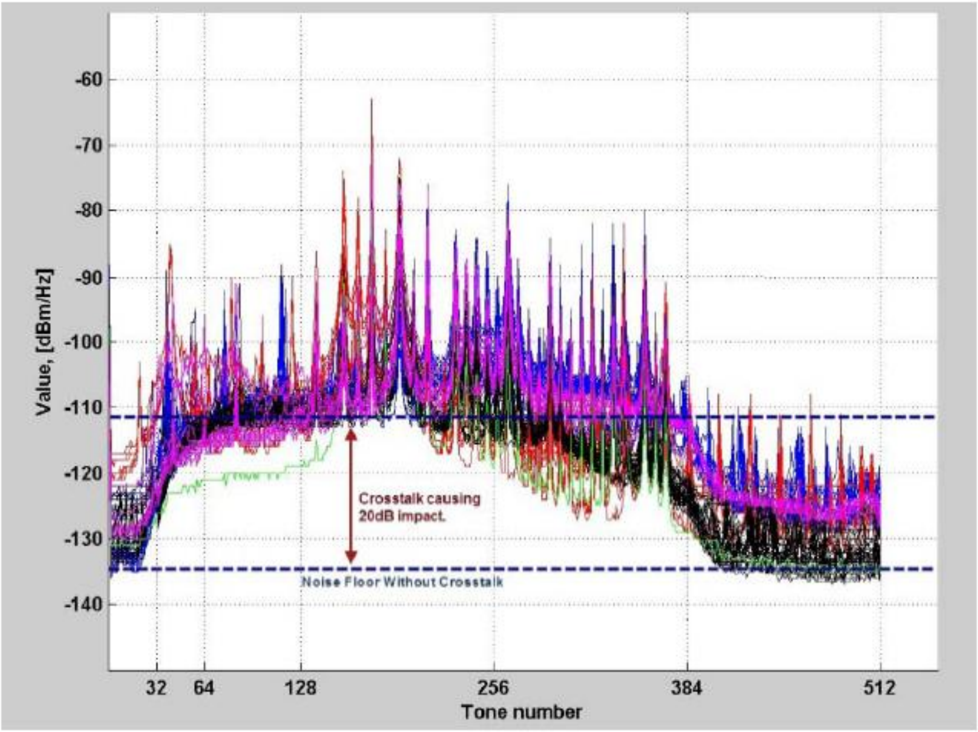


Figure 25: Crosstalk effect on noise floor

With the introduction of the cognitive systems in the access network, the virtualization of binders was possible with the GIS application, while the grouping of lines that could reduce power was done in a batch way. Even though the outcome of these actions could not be measured, field trials shown that a 20dB reduction in the average noise across an ADSL2plus spectrum (512 tones) would result in a 10Mbps data rate reduction. [11]

Prequalification

In the absence of that platform, when planning DSL line configuration for maximum reach or rate the operator had two approaches to choose from:

- Aggressive pre-qualification. This way, pre-qualification rules were primarily based on parameters related to loop topology, taking only a moderate noise environment into account. This was leading to an increased level of instability, resulting in more customer complaints and follow-up costs.
- Conservative pre-qualification. With this approach, pre-qualification was taking into account both loop topology and impulse noise using a static model based on worst-case

assumptions. Clearly, the drawback of this approach was the drastically reduced service coverage on high bit rates and a higher opex.

With the use of the platform, the prequalification of every line was more efficient. Copper faults were identified before or upon the service activation and treated respectively. The different network elements were provisioned to serve the purchased service with the appropriate settings.

The average time of the first customer complaint on new service activations, was before 2 weeks. After the correct prequalification workflow, the related time was extended to 2 months. The total cost of resolution that for that first complain reduced to half. The benefit of the positive approach on service on newcomers was increased by 80%.

Complain resolution cost

Before the cognitive approach implementation, the cost of ticket resolution was high due to the extensive time the identification and resolution was needed. Afterwards, the man hours for the ticket resolution, strictly related to the access network, was reduced to 60% for the 3rd level of customer support. The relevant reduction of the 2nd level was 53% while for the 1st 42%.

The result of the proper actions of customer support and service provisioning, reduced the user complains, while at the same time gave a better indication of the operator's possible network problems. It was calculated for the first month that the user complains with the introduction of DLM was initially reduced by 5%. This percentage was tripled after 3 months period, as the stakeholders of the organization were more familiar with the new approach and the operational workflows of each department were tuned to adapt to the new facts.

The overall cost for the operator of the tickets was in the end rolled to the monthly fee of the subscription. The operator was able to have a 9% more profit out of the service, though in the end applied a lower subscription fee, in order to be more cost efficient on the already high competition.

Churn reduction and loyalty

As a more professional approach was adopted on every customer complain, eventually the technical problems were reduced or solved immediately. Marketing campaigns indicated before the implementation of the cognitive that the 1st reason for churn on the operator was the inability to solve some technical problems. A high percentage also indicated the longtime of resolution and call waiting on the different levels of customer support. Another indicator presented that a part of the churn was on the newcomers, as their service was not as good as on the previous operator, or the service was unstable at all.

The repetitive same campaigns presented a reversed aspect just after 3 months of operation. The loyalty of the new subscribers was high, as subscribers reported better service than the previous operator. The long time for resolution was not reported anymore, while the technical problems were in the bottom of the list for the reason of churn.

IPTV penetration

The operator was under consideration for the introduction of IPTV platform, as a revenue increase method. The low penetration of IPTV as far as the synchronization rate and the instabilities of the network were the difficulty of the cost-benefit analysis for that project. As mentioned before, IPTV scenarios require at least of 6mbps actual bitrate in the downstream direction.

The increase in the synchronization rates made the penetration of IPTV 11% higher than before. The improvements in stability and the new sophisticated method of work, guarantees the overall lower cost of operations and maintenance low. These facts make the investment in IPTV as of lower risk and OPEX intensive.

VDSL2, targeted sales and marketing campaigns

The oncoming next generation access technology for that country was the VDSL2. VDSL2 emitted from the central offices, as a low cost investment to see the future trend, was also under consideration from the operator. The VDSL2 though, has a benefit on subscribers with loop lengths up to 1,5km. The operator had a difficulty with the prediction of that on an existing subscriber and a new comer. The cognitive control over the access network gave the possibility to geographically predict and qualify areas where the VDSL2 service could be offered. For every subscriber in these areas the possible attainable rate was calculated

The outcome of these was the feedback to the operator, regarding in which central offices will benefit the most with the use of VDSL2. Efficiency in planning network resources was achieved. The prediction of the VDSL2 service was possible even for possible now comer subscribers.

With innovative geodemographic segmentation solutions from the GIS location intelligence, penetration rates, xDSL classification for stability and performance, comparing and analyzing direct marketing campaigns to existing and potential customers, and lots of more are available to optimize company strategies and increase sales.

Conclusions

With the rollout of triple play services, the copper infrastructure is used more intensively than during the early deployment phase of internet access services. With the higher use, the sensitivity of the DSL to the environment is increased. As a result, the problem of line instability must be addressed. Line instability is induced by noise interference characterized by unpredictable non-stationary behavior. Instability is measured to be very OPEX intensive for fixed operators. The replacement of copper with fiber is a technical solution, though requires mass investments in a high risk environment. For this reason, emphasis is given to solve such copper administration problems from the vendors and the operators.

A solution to such problems always comes from the network management systems perspective. In this case, it is the cognitive systems that have the knowledge of highly experienced technicians, modelized as system functions; with relevant workflows that automatically decide configuration changes, or provide feedback regarding the proper resolution actions; with actions that are transparent upon different vendor platforms and are based on standardized equipment modules. Cognitive Copper management systems are tools that must be seen as core platforms for integration with service provisioning, assurance (trouble ticketing), performance and trend prediction tools.

Initiatives of vendors or organizations have been done towards dynamic configuration management, as such as the ones of Broadband forum tr-198. Their purpose is to develop solutions that enable pro-active and efficient maintenance of broadband services over copper lines. The drawback on these initiatives it that they focus only on dsl related aspects, ignoring the value of GIS systems, narrowband line tests and other valuable statistics generated from application servers and other network elements.

It is of paramount importance for an operator to have workflows with access to advanced troubleshooting and planning tools: DELT, SELT, NBLT, dsl performance data, GIS tools, BRAS and AAA statistics are the most important but probably not the only ones that can be used in the cognitive approach. These tools may give a system the ability to model the offered services with the relevant quality of experience. These combined with the functions of performing configuration changes and follow organizational workflows, are the core functions of a modern cognitive copper administration system.

The results of the use of the cognitive copper administration on a European operator prove that cognitive management systems are the trend towards operation excellence and economic sustainability. The improvement on stability and performance is the technical value of such systems. The economic impact has also measurable factors like the lower costs on call centers, reduced power consumption, reduced churn. Some other factors though cannot be measured: efficiency in resource planning, customers' satisfaction and loyalty, assisted targeted sales and marketing campaigns.

Cognitive copper administration allows all lines to operate near their optimal performance with minimal impact on other lines in the binder. Operators with DLM tune their network to function at the maximum stable rate, offering the possibility to supply innovative, revenue-generating services on their optimized network.

Appendix I - References

[1] International Telecommunication Union - Telecommunication G.992.5**,** *Asymmetric Digital Subscriber Line (ADSL) Transceivers-Extended Bandwidth ADSL2 (ADSL2plus)*

[2] Alex Gillespie (2001): *Broadband access technology, interfaces and management*, ch13

[3] International Telecommunication Union – Telecommunication G.998.1: *ATM-based multi-pair bonding*

[4] International Telecommunication Union – Telecommunication G.998.2: *Ethernet-based multi-pair bonding*

[5] Peter J.W. Melsa & Krista S. Jacobsen (2003): *Single-Ended Loop Testing (SELT): Expectations and Realities*, White Paper, Texas Instruments, Broadband Communications Group

[6] Ian Cooper (2006): M TF2.5 - First-mile layer one architecture issues for Zero Touch service provision

[7] Broadband Forum TR-202 (2002): *ADSL2/ADSL2plus Low-Power Mode Guidelines,* TR-202 Issue 1 Feb 2002

[8] ND1424: *Guidelines on DSL power saving models and nonstationary noise in metallic access networks* NICC 02/2008

[9] http://www.friendly-tech.com/solutions/fixed-line-xsps/device-management.aspx

[10] Mavroidis Athanasios, Karamitsos Ioannis, and Saletti Paola(2009): Qualification and Provisioning of xDSL broadband lines using a GIS approach

[11] J.M. Cioffi, S. Jagannathan, Hao Zou W. Lee, Aakanksha Chowdhery, W. Rhee, George Ginis, and P. Silverman(2008): “Greener copper with dynamic spectrum management”

Appendix II – List of figures and tables