



DB2.3 - Migration guidelines for DSL from operator's view

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ABBREVIATIONS

ADM	All Digital Mode
ADSL	Asynchronous Digital Subscriber Line
ATM	Asynchronous Transfer Mode
ATU-C	ADSL Terminal Unit – Central Office
ATU-R	ADSL Terminal Unit - Remote
BRAS	Broadband Remote Access Server
CAP	Carrierless Amplitude and Phase
CAPEX	Capital Expenditure
CC	Continuous Connectivity
CPA	Converged Packet Access
CPE	Customer Premises Equipment
CoS	Class of Service
CVoDSL	Channelised Voice over DSL
DAVIC	Digital Audio-Visual Council
DEC	Digital Echo Cancellor
DHCP	Dynamic Host Configuration Protocol
DLCM	Dynamic Line-Code Management
DMT	Discrete Multitone
DNS	Domain Name Service
DP	Distribution Point
DRR	Dynamic Rate Repartitioning
DSL	Digital Subscriber Line
DSLAM	Digital Subscriber Line Access Multiplexer
DSM	Dynamical Spectrum Management
EFM	Ethernet in the First Mile
EFMC	Ethernet in the First Mile Copper specifications
EFMF	Ethernet in the First Mile Point-to-Point Fibre specifications
EFMP	Ethernet in the First Mile Point-to-Multipoint Fibre specifications
E-LAN	Ethernet LAN
EMC	Electromagnetic Compatibility
EMF	Ethernet Metro Forum
EoATM	Ethernet over ATM
EOC	Embedded Operations Channel
EPON	Ethernet Passive Optical Network

ETSI	European Telecommunications Standards Institute
FDD	Frequency Domain Duplex
FEC	Forward Error Correction
FEQ	Frequency Domain Equalizer
FSAN	Full Service Access Network
FTTx	Fibre-to-the-X (x: Ex=Exchange, Cab=Cabinet, C=Curb, B=Building, H=Home)
GbE	Gigabit Ethernet
GPON	Gigabit Passive Optical Network
HDSL	High-bit-rate Digital Subscriber Line
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IGMP	Internet Group Management Protocol
IMA	Inverse Multiplexing over ATM
INP	Impulse Noise Protection
IP	Internet Protocol
ISDN	Integrated Services Digital Network
ISP	Internet Service Provider
ITU-T	International Telecommunication Union –Telecommunication Standardization Sector
LAN	Local Area Network
LDPC	Low-Density Parity Check
LEx	Local Exchange
LLU	Local Loop Unbundling
LR	Long Reach
LT	Line Termination
MAC	Media Access Control
MDF	Main Distribution Frame
MEF	Metro Ethernet Forum
MEN	Metro Ethernet Network
MIB	Management Information Base
NT	Network Termination
NTE	Network Terminating Equipment
OAM	Operational Administration and Maintenance
OLT	Optical Line Termination
ONU	Optical Network Unit

OPEX	Operating Expenses
OSI	Open Systems Interconnection
PC	Personal Computer
PON	Passive Optical Network
POS	Packet Over SONET
POTS	Plain Old Telephone Service
PPP	Point-to-Point Protocol
PSD	Power Spectral Density
P-t-MP	Point to Multipoint
P-t-P	Point to Point
PVC	Permanent Virtual Circuit
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
RADIUS	Remote Authentication Dial-In User Server
RADSL	Rate Adaptive Digital Subscriber Line
REIN	Repetitive Electrical Impulse Noise
RFI	Radio Frequency Interference
SDH	Synchronous Digital Hierarchy
SDSL	Symmetric Digital Subscriber Line
SHDSL	Symmetrical High Bit-rate Digital Subscriber Line
SLA	Service Level Agreement
SNR	Signal-to-Noise Ratio
SONET	Synchronous Optical Network
SRA	Seamless Rate Adaptation
STM	Synchronous Transfer Mode
TDM	Time Division Multiplexing
TEQ	Time Domain Equalizer
TPS-TC	Transmission Protocol Specific – Transmission Convergence
TS	Technical Specification
USB	Universal Serial Bus
VC	Virtual Channel
VDSL	Very high bit-rate Digital Subscriber Line
VLAN	Virtual Local Area Network
VoIP	Voice over IP
VPN	Virtual Private Network

WDM

Wavelength Division Multiplexing

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EXECUTIVE SUMMARY

This deliverable aims to give an operator view on the DSL migration and as such guide innovations in other deliverables in MUSE. DB2.3 starts from DA2.3 but goes more into the details of the DSL network part that includes protocols and functions on OSI layer 1 and 2.

Chapter 1 gives an overview about the current situation of most DSL operators. A typical broadband service deployment is described including the infrastructure and network architecture situation.

Chapter 2 identifies motivations and guidelines for migration from current DSL deployments to next generation DSL starting from current network situations and involving technical analysis results of MUSE. Migration steps are described starting from an ADSL base to VDSL2.

The Introduction of enhanced or new DSL flavours is driven by:

- Low cost bandwidth upgrade,
- Low cost reach upgrade,
- Low cost service enabling,
- Reduction of operation expenses.

The chapter discusses some features of a new DSLAM generation which give the operator the needed migration flexibility. An advanced Ethernet/IP DSLAM should be able to substitute the installed ADSL base by providing line cards which support ADSL lines. Where the availability of VDSL2 techniques is insufficient, the DSLAM should support ADSL2+ line cards. Later, the DSLAM can be populated with VDSL2 line cards which enable ADSL2/2+ or VDSL2. In addition, it is necessary to support an appropriate optical feeding system to connect remote DSLAMs on the basis of FTTCab or FTTB.

The FTTCab concept enables to reach the majority of customers with very high data rates provided by ADSL2+ or VDSL2. There are however also large initial investments for the FTTCab concept due to the high effort for the new optical infrastructure, the usually required upgrade of the existing Cabinet locations regarding outside capability, power supply and air-conditioned environment. On the other hand, in urban areas the Main Cable section usually has a large installed duct base that enables a cost optimized fibre roll-out up to the Cabinet. Chapter 2 discusses some concepts to keep down the investments for the Cabinet location (Mini DSLAM with remote powering, Central cabinet migration concept with local powering and VDSL over optics). In addition, alternative remote powering concepts are described including some quantification of what is possible in terms of reach and output wattage.

Two migration paths were identified. Migration Path 1 (CAPEX minimised, low risk migration) aims at a mass market roll out and minimises the economical risk in case the customer penetration slowly increases. Migration Path 2 is an option for services offering with data rates higher than 25 Mbit/s that requires more and more an FTTB approach. On the other hand it is the most suited solution for deployment in selected areas with powerful duct (fibre) infrastructure (dense urban, urban areas), where FTTB becomes cost competitive to FTTCab, where it is not possible to install new street cabinets, where alternatives are too expensive, or in areas with high competition (strategic positioning).

Chapter 3 discusses migration aspects of different xDSL technologies. Migration motivations have been identified for ADSL2, ADSL2+, VDSL1 and VDSL2.

VDSL deployment in the cabinet would prevent simultaneous VDSL deployment in the exchange over the same cable plant using the same power spectrum and band plan. This is because downstream signals injected at the cabinet will be much stronger in the final section of cable than signals in adjacent pairs injected at the exchange. This has the consequence that the FEXT caused by cabinet systems will tend to drown the weak signals arriving from the exchange. This effect is known as the near-far problem.

Chapter 3 discusses the evolution and migration path to DSM and DLCM. There seem to be no fundamental conflicts between the MUSE architecture proposals and the development of Dynamical Spectrum Management (DSM) and DLCM. The pathway to DLCM deployment is somewhat clearer than is the case for DSM. Using proprietary intelligent management systems it is already possible to gain advantages from line-by-line performance monitoring and selective adjustment of line coding parameters. There seem to be no fundamental regulatory implications

Chapter 4 identifies Carrier requirements for Ethernet based DSL with the focus on Operations, Administration and Maintenance (OAM). Today, Ethernet does not provide a standardised end to end OAM communication **which allows to supervise the whole path between RGW and ASP**. Link OAM specified by IEEE 802.3 Clause 57 only enables to monitor and troubleshoot an individual Ethernet link.

The existing IP troubleshooting protocols (e.g. SNMP, IP Ping, IP Traceroute), which are often used to manage Ethernet networks, will not work unless the Ethernet layer is operating properly. In addition, this requires an IP overlay for management and troubleshooting of layer 2 Ethernet.

Management protocols are required which provide per-customer or per-service granularity to manage the individual layer 2 Ethernet service connections provided to customers. In addition, such protocols should support p2p, p2mp and mp2mp connectivity.

IEEE 802.1ag specifies Service OAM that provides monitoring and troubleshooting of end-to-end Ethernet service instances. It is recommended to consider this specification for the GSB standard.

A general problem of hybrid ATM/Ethernet scenarios is the interruption of the established ATM-based OAM flows by the Ethernet network part. This requires an introduction of new OAM processes, including mapping mechanisms between ATM-based and Ethernet-based OAM procedures.

Chapter 4 discusses Ethernet migration and integration options starting from the existing ADSL platform. In general there are two possible ways to introduce Ethernet in the Access platform:

- Migration model: Ethernet solution substituting existing ATM based DSL platform parts and,
- Overlay model: Ethernet solution running in parallel to ATM based DSL connections.

The described intermediate migration options have serious drawbacks complexity and additional efforts combined with intervention in running systems. A temporary coexistence of both transport layers in separated parallel DSLAM platforms in the access domain is a more realistic approach.

1 INTRODUCTION

1.1 Objectives

DB2.3 starts from MUSE Deliverable DA2.3 on Network Architecture Migration, but goes more into the details of the DSL network part that includes protocols and functions on OSI layer 1 and 2.

The main objective is to identify motivations and guidelines for migration from current DSL deployments to next generation DSL and Ethernet, including aspects of network management. The migration guidelines will be identified starting from current network situations, involving technical analysis results of MUSE.

These guidelines do not imply that there exist any actual plans, road maps and schedules of particular network operators to execute or use these migration guidelines. The application is left to the network operators.

1.2 Current situation - Common aspects for most operators

The current situation is the starting point of evolution, which is based on inputs from the network operators involved in MUSE. Clearly the present status in each country will be different depending on the starting point, the degree of evolution and commercial and regulatory pressure. A generalised picture of the current situation is presented here and exceptions are noted.

1.2.1 *Typical Broadband Service Deployment*

The typical broadband deployment is based on ADSL over POTS technology for Internet services for residential customers and ADSL or SDSL for business customers. Downstream bit-rates usually range from 1Mbit/s to 4Mbit/s. This service offer considers a classical situation where we have:

- ADSL modems with USB or Ethernet connections to the PC or combined ADSL modem/Ethernet router
- DSLAMs with STM1 interfaces
- an ATM aggregation network
- the BRAS connected to an ISP router through an IP backbone

1.2.2 Infrastructure situation

Most of the European telephony local loop networks were built around the middle of the past century by the national telecom operators. The local loop provided a dedicated wire pair from each house in an area to the local exchange (LEx). Figure 1.1 shows a typical topology for the local loop network. A thick binder cable, the main cable, runs from the local exchange to a street cabinet. From the street cabinet a number of distribution cables emerge containing a smaller number of wire pairs. These distribution cables end in the street, for example in an external or a buried connection box, from where a “drop” cable with one or two wire pairs runs to each house. Typically a cable with smaller gauge wires inside is used between the exchange and cabinet than from the cabinet to the distribution point because in this way, the overall size of the bundle of cables is more manageable there where the number of cables is higher. It should be emphasized that this topology cannot be generalised; on a national scale, and regionally or locally, variations of the topology are found. Some short lines may go directly to a DP rather than via a cabinet. Although cables were designed to optimally carry analogue voice signals, a large variety of cable designs that meet this criterion is possible. This will lead to significant variations regarding crosstalk performance and loss and it may impact on the reliability of the network. The mix of underground and overhead cables will also impact on DSL performance. In the UK, the ratio of underground to overhead is about 50:50, whereas Germany has a much greater percentage underground.

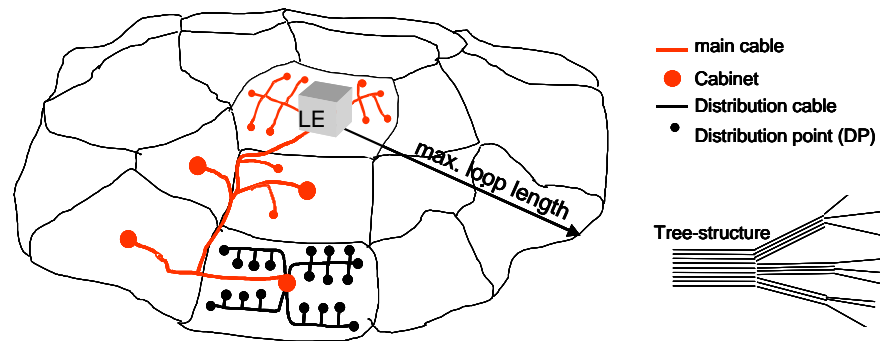


Figure 1.1: Architecture of first mile network areas

Because the figure shows a simplified and generalised model, it is unlikely that any European network is exactly portrayed, but it gives a reasonable impression of a typical network. In addition, the local exchange area is governed by the reach of analogue telephony which is further than that of DSL.

One issue which has a significant impact on predicting DSL performance and will impact on migration is the accuracy of cable records and whether there is automated access to the records.

A Local Exchange Area consists of several flexibility points and link levels. The flexibility points, which allow access, are:

- Main Distribution Frame (MDF) located in the local exchange (LEx)
- Passive Cabinet (Cab) without powering and cooling located at the roadside
- Distribution Point (DP) typically located at/in the buildings (DP)

The copper cable connecting the flexibility points are distributed by branching boxes. These connections constitute the main and the distribution networks. Figure 1.2 shows the flexibility points and link levels within a typical European access network.

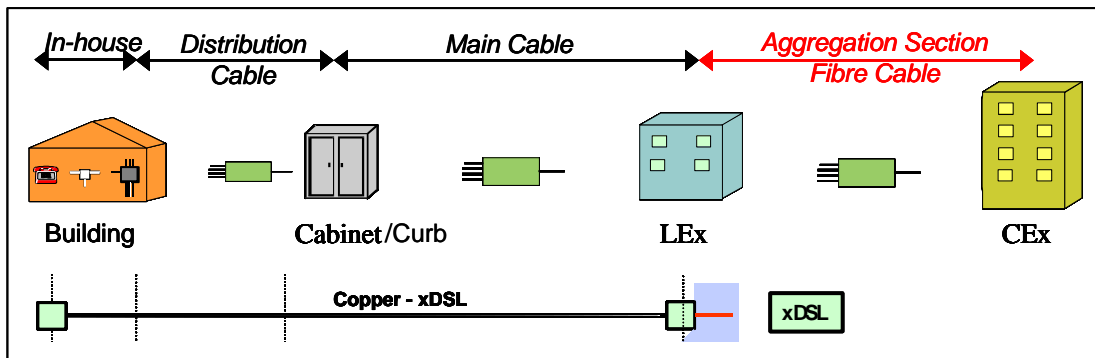


Figure 1.2: Typical European access network model

1.2.3 Network architecture situation

The network architecture addresses the part between the IP edge node including the BRAS function and the Customer Premises. The incumbent access network architecture today is mainly ATM based and delivers pure best effort services via Point-to-Point-Protocol (PPP) over ATM (PPPoA) or PPP over Ethernet over ATM (PPPoEoA) for the mass market without any QoS mechanisms. The BRAS builds the single edge service connection point which represents a centralized approach. The DSLAM location is the Local Exchange. Depending on the total number of customers one or more Slave DSLAMs are connected to one Master DSLAM. Today in general the broadband service offer does not include any in-band complete voice solution. Only few special VoIP offers inside the IP domain are available mainly concentrated in one service provider environment without any guarantees. The ATM layer offers the mass market customer only one VC with Best Effort UBR, which is normally overbooked in the range of 1:10 up to 1:20. Figure 1.3 shows the less evolved status of the current architecture as a reference for all migration scenarios starting from the existing ATM based network architecture.

The session initiation can be described as follows:

- The customer initiates the PPP tunnel via an ATM PVC;
- During the Authentication procedure the BRAS requires from the RADIUS server the confirmation after checking up the customers profile with the database;
- The RADIUS server determines the dynamic IP address (IPv4) which is only valid for the session duration;
- The BRAS initiates the connectivity to the service provider depending on the customer profile;

The access network is divided into an aggregation network and first mile network. The aggregation network infrastructure is mostly fibre based, usually without any WDM-technology. Different network topologies like star, ring or mesh are present. Today's aggregation network is divided in different platforms like SDH and ATM, whereas IP is usually transparently transported over ATM and SDH respectively up to the edge node. In order to reduce the overall investments and running costs as well, the challenge will be the design of a universal aggregation platform with a common Layer 2 (L2) transport technology which is able to carry all services and to support all connected first mile solutions. The first mile segment is mostly copper based in contrast to the aggregation network. However, these technologies are limited in both reach and bandwidth depending on the real copper plant.

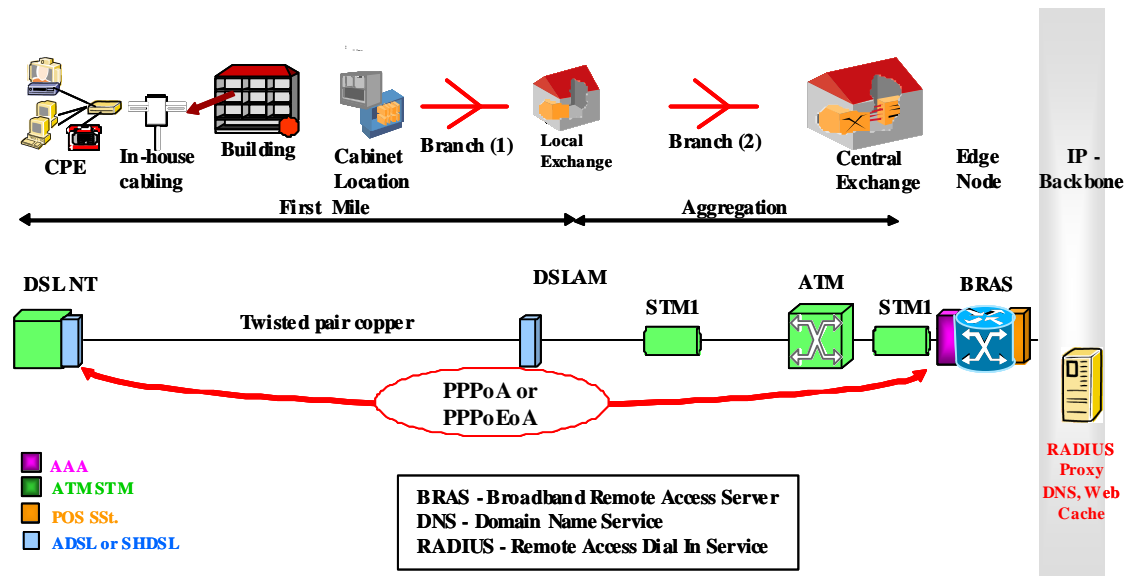


Figure 1.3: Reference scenario

2 DSL MIGRATION GUIDELINES

2.1 Introduction

DSL technologies allow to use the POTS copper infrastructure to offer broadband services. However, DSL solutions are limited in reach and bandwidth depending on the real copper plant. In general, beyond the 8 Mbit/s downstream rate, it will be more and more necessary to move the optical fibre techniques from central office closer to the customers. Optical access nodes have to move towards the first mile network locations (e.g. cabinets, buildings). This requires the roll-out of new optical fibre cables and the installation of optical equipment at a large number of locations including new housing and powering requirements. Such a platform upgrade causes high initial investments in the first mile segment. To keep down the costs different DSL migration possibilities should be considered. These guidelines discuss some DSL migration options, according to an operator's point of view, depending on different roll-out strategies and Customer/Service Bandwidth demand scenarios.

2.2 General Motivations for DSL Migration

In general, DSL operators have a large installed ADSL base. But what can motivate an operator to change the running DSL access platform? This section discusses some aspects that drive a migration towards advanced DSL technologies.

Low cost bandwidth upgrade

The main driver is the increase of subscriber bandwidth (bit-rate) enabling the operator to offer new or additional services and to satisfy the increasing demand of the customers. Enhanced DSL technologies focus mainly to advance the bit-rates.

Usually an upgrade of the subscriber bandwidth requires a technology exchange or capacity extension in the Access or Aggregation Domain, for example the installation of a VDSL system in the Access Domain or additional aggregation nodes, interfaces and links in the Aggregation Domain. Ethernet is expected to provide cost advantages, compared to ATM based systems.

Low cost reach upgrade

The general attribute of copper transmission technologies is the bandwidth-reach limitation. A strong motivation for operators to get a system reach extension is to offer a broadband service to more customers, which are up to now too far from the Local Exchange. Another aspect of longer reach is the possibility to concentrate more subscribers (usually widely spread) to one DSLAM equipment.

Like for the bandwidth upgrade case, an extension of the DSL reach requires new techniques in the Access Domain. The operator has the choice between ATM/SDH-based or Ethernet-based DSL systems and it is expected that Ethernet is the cost optimized variant.

Reduction of operation expenses

The operation expenses are a very important aspect for the operator in order to optimise the costs per line. It contains expenditures for Operation, Administration, Maintenance, Provisioning and Management. Enhanced DSL technologies aim e.g. at power management which not only improves the transmission capabilities of the cable but also leads to reductions of power consumption. DSLAM concepts with remote powering, higher DSL port density and lower heat dissipation could be realised connected with lower installation costs and better reliability.

Ethernet may enable a reduction of the running costs due to its simplicity (Plug & Play, Point & Click provisioning,...). As Ethernet is more commonly known among data communication engineers, training costs are expected to be lower than for ATM. The same OAM capabilities however need to be provided in a carrier grade Ethernet network as they are known for ATM.

Low cost service enabling

As the DSL Operators offer mainly only one service, the "Internet Access", today the ATM QoS capabilities are not implemented within the DSL platforms. But the trend towards "Triple Play" (Voice, Video, Data) requires a support of multiple Service classes with different QoS characteristics. Ethernet is able to provide several service classes (CoS). Ethernet can enable new Layer 2 VPN services by its Switching layer, e.g. the Ethernet LAN (E-LAN) service type standardised by the Metro Ethernet Forum (MEF). Additionally, Ethernet has the potential to offer a low cost enabling of special functionalities, e.g. Efficient Multicast support, IGMP Snooping support. Such capabilities are also feasible in ATM, but the component industry promises a lower cost implementation in Ethernet, due to the economies of scale.

2.3 Migration discussions

It is difficult to describe generally admitted DSL migration guidelines because usually each network operator has to balance a set of different local parameters. The decision of which broadband roll-out strategy should be preferred depends not only on an operator's business case that includes a broadband service demand. In addition, the operator has to consider his infrastructure and network architecture situation, regulation and competition aspects and, last but not least, the migration should be future-proof.

2.3.1 Future-proof DSL

The DSL migration concept has to fit in operator's network evolution strategy, which means that a future-proof DSL technology is needed.

The ITU-T Recommendation for Very-high-bit-rate Digital Subscriber Line 2 (VDSL2) offers a range of interesting migration aspects for a cost efficient upgrade of the existing xDSL-infrastructure. The VDSL2 standard, G.993.2, was approved and announced by the ITU-T on May 27th, 2005.

VDSL2 is backwards compatible and interoperable to ADSL, ADSL2 and ADSL2+ that enables a smooth, gradual and flexible upgrade of existing networks according to market demand and various regional network requirements.

Figure 2.1 describes a possible migration path from an ADSL2+ set-up towards a combined ADSL2+/VDSL2 network. Starting in Phase 1 with a large ADSL2+ base the DSLAMs will be upgraded with VDSL2 line cards in Phase 2. In case a DSLAM upgrade is impossible a new DSLAM generation must be introduced. The existing ADSL lines can be moved to the new line cards and the customers have not to change the CPEs. In Phase 3, a selective upgrade of ADSL2+ or VDSL2 CPEs is possible dependent on the selected service. Such a single network can be maintained to provide the entire xDSL services portfolio while reducing deployment, operating and maintenance costs.

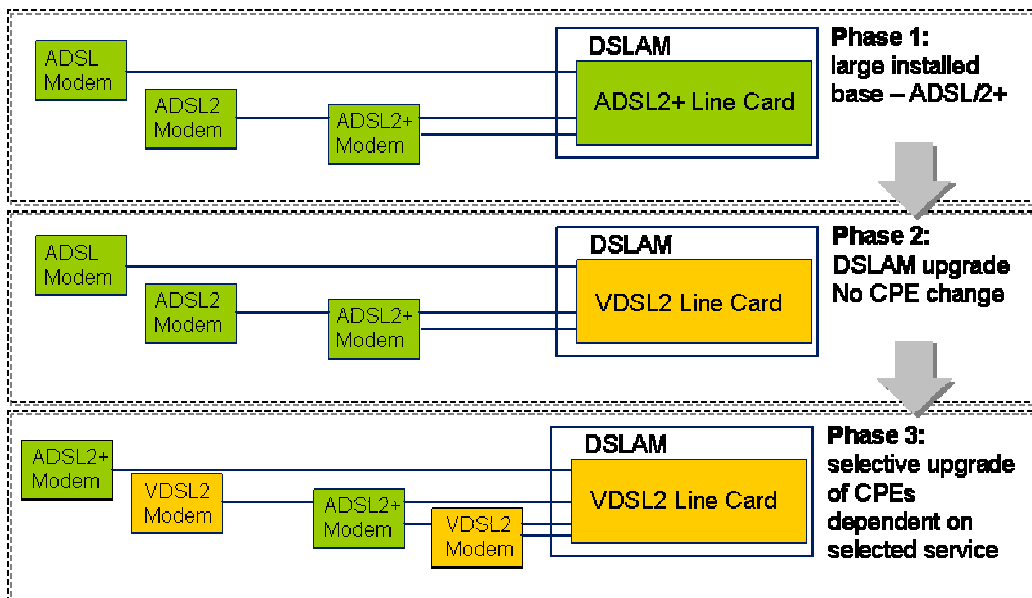


Figure 2.1 ADSL to VDSL2 migration

The VDSL2 standard provides symmetric data rates up to 100Mbit/s depending on the loop-length and ADSL-like data-rates with ADSL long reach capability. Long-Reach-VDSL2 enabled systems are capable of supporting downstream data rates of around 1-4 Mbit/s over distances of 4 to 5 km, gradually increasing the bit rate up to symmetric 100Mbit/s as loop-length shortens. It includes Echo Cancellation and Time Domain Equalization to reach required performance for medium and long loop applications above 1-1.2km. On the one hand, VDSL2 supports a substitution of existing ADSL services and, on the other hand, it enables the introduction of new services due to its bandwidth performance.

An important aspect of a future-proof DSL technology is the supported Layer-2 protocol. VDSL2 as well as VDSL1 support interfaces to Ethernet and ATM on Layer-2. This enables Ethernet end-to-end system solutions without any ATM layer in opposite to all ADSL techniques using ATM. So VDSL2 can be used for Ethernet or ATM environments.

The new VDSL2 standard offers QoS features for delay-critical applications. The Pre-emption mechanism gives higher priority to the delay-critical voice and video packets over other data packets such as email messages, web-pages etc.

The handling of different data rates will be supported by Dual latency (two independent latency paths), Dual interleaving (better noise protection and higher security), and 2 bearer channels (for transport of user information) improve the efficient and reliable handling of different data rates.

VDSL2 includes all the benefits of ADSL/2+ with higher speeds than VDSL1. It offers the chance of a gradual, flexible, and cost efficient upgrade of the existing xDSL platform. Additionally, it supports Ethernet or ATM on Layer-2. So it seems to be the ideal DSL technology. But currently there is only a low availability of VDSL2 techniques because the standard was approved and announced by the ITU-T on May 27th, 2005. As VDSL1 has no ADSL compatibility, it makes sense to migrate via an ADSL2+ solution that allows a VDSL2 upgrade.

2.3.2 DSL starting from the Local Exchange

To keep down the high initial investments for the optical deployment in the first mile segment, the Fibre To The x (FTTx) solutions offer the chance for a smooth migration by deploying hybrid fibre/copper networks. The xDSL DSLAM will be pushed towards the customers and fed by fibre. The existing copper cable flexibility points of the traditional access network are to be considered. These are the Local Exchange, the Distribution Cabinet that is the demarcation point between the main cable and the distribution cable, and the In-house Distribution Points terminating the In-house cabling. The corresponding concepts are called Fibre-To-The-Local-Exchange (FTTEx), Fibre-To-The-Cabinet (FTTCab) and Fibre-To-The-Building (FTTB).

An FTTEEx approach means DSL starting from the Local Exchange (LEx). According to the operator's point of view, the LEx is an ideal location to introduce new techniques because there are powering, air-conditioned environment, footprint for telco racks, etc. But each DSL technology has specific reach limitations so that more or less customers of a Service Area can be connected depending on xDSL type. In general, the higher the data rates the lower is the reach. However, also the FTTEEx approach makes sense for high rate ADSL2+ or VDSL2 solutions and can be seen as a migration step. As shown in Figure 2.2 usually there is a part of a Service Area around the Local Exchange that can be reached by a specific high rate DSL technique without any infrastructure workings. Especially in urban areas, a considerable number of customers can be connected on the basis of ADSL2+ or VDSL2.

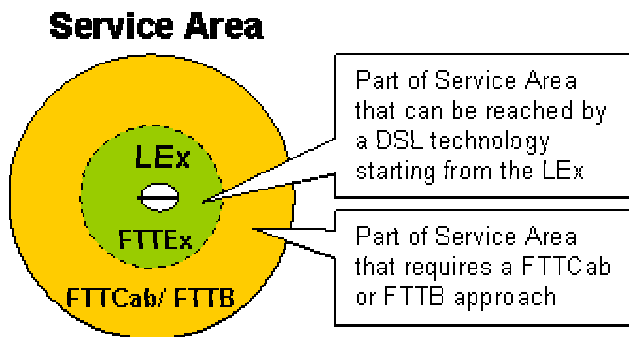


Figure 2.2 FTTEEx limitations

The offering of a new Service generation that is optimised for packet oriented traffic with very high data-rates and Quality of Service (QoS) provision, probably requires the introduction of a new DSLAM generation. Considering the state-of-the-art it does not make sense to upgrade the platform on the basis of ATM DSLAM techniques with ATM uplinks. Figure 2.3 depicts some features of a new DSLAM generation which give the operator the needed migration flexibility. An advanced Ethernet/IP DSLAM should be able to substitute the installed ADSL base by providing line cards which support ADSL lines. Where the availability of VDSL2 techniques is insufficient, the DSLAM should support ADSL2+ line cards. Later the DSLAM can be populated with VDSL2 line cards which enable ADSL2/2+ or VDSL2. In addition, it is necessary to support an appropriate optical feeding system to connect remote DSLAMs on the basis of FTTCab or FTTB.

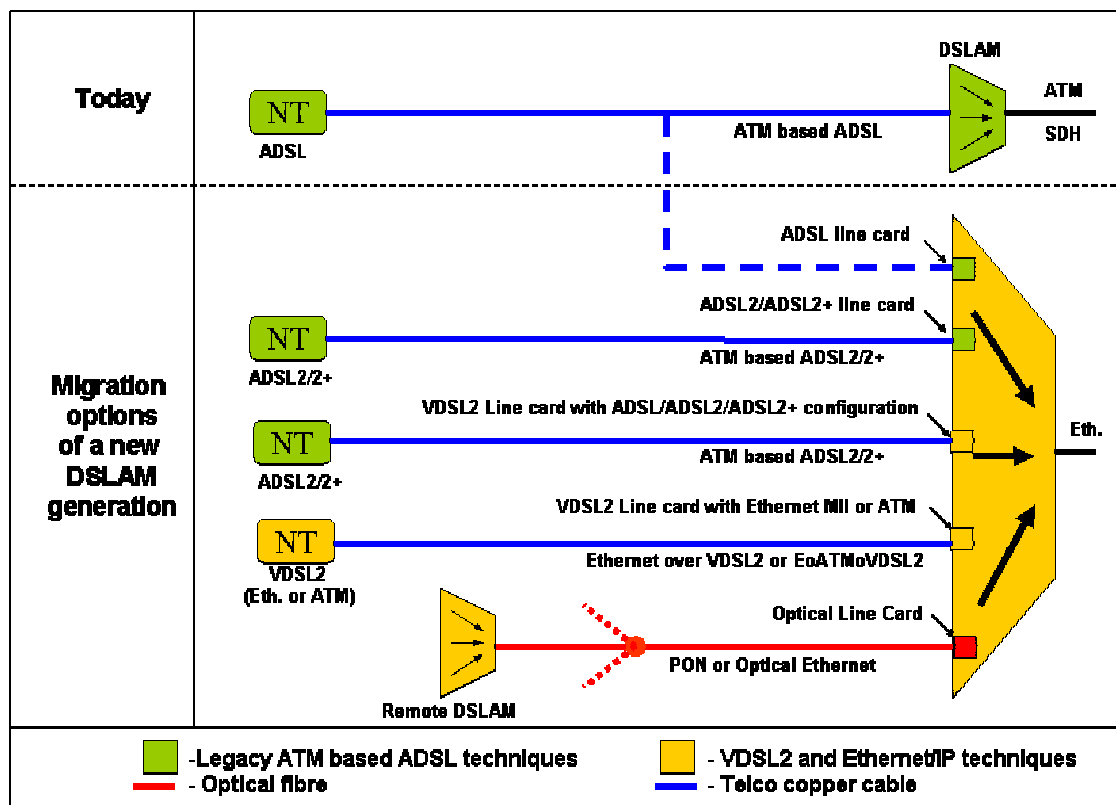


Figure 2.3 Migrations options of a new DSLAM generation

Note: A platform upgrade on the basis of different DSL technologies in parallel usually requires a Spectrum Management.

In general, a crucial concern is the spectral condition within the copper cables and their impact on neighbouring quadruple bundles. To optimise this performance the ETSI-workgroup (WG TM6) proposes a managerial approach based on mandatory rules for achieving access to the local loop wiring equal for all DSL operators that use the same network cable and voluntary rules proprietary for each individual DSL operator, which reflects the DSL operator's own view regarding the maximum length and maximum bit rate to ensure its DSL service. At the moment, the DSM mechanisms are arising at the horizon. They represent a promising approach for performance optimisation of the copper plant.

An alternative to overcome the reach or bandwidth restrictions could be the “Bonding of pairs”. The data transmission will be distributed over 2 or more copper pairs so that the rate per pair decreases and the reach increases. ADSL2+ as well as VDSL2 supports such bonding mechanisms. But especially the main cable sections between the LEx and the cabinets/curb are strongly limited by the number of spare copper-wire which excludes the “Bonding of pairs” for the mass-market.

As described in the MUSE document DA2.3 (Network architecture migration mechanisms – consolidation) a transgenerator concept offers an additional solution to increase the Service Area coverage of a Local Exchange.

A “Mini” transgenerator that provides 8 to 12 DSL lines could be installed at existing Distribution Cabinets. Such a device should be able to support remote powering due to the small number of DSL lines and thus low power budget. Remote powering can be realized using spare copper pairs of the Main cable (Figure 2.4).

This concept could help Operators to keep down the initial investments if the customer penetration is low. In case the penetration allows an efficient upgrade a migration to a FTTCab solution can be considered.

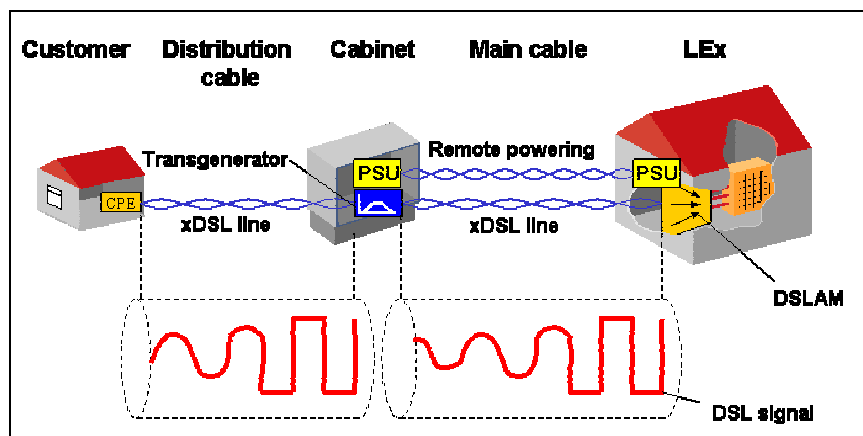


Figure 2.4 Transgenerator concept

2.3.3 FTTCab migration

In order to exploit the higher bandwidth capabilities of advanced DSL-technologies also in the part of the Service Area that can not be reached by a specific high rate DSL type, the optical fibre has to be used to bridge a section of the Service Area to bring the DSL closer to the customer.

The FTTCab concept represents a beneficial solution for a DSL migration. It aims on the possibility to use the Distribution (Street) Cabinet in order to install a Remote DSLAM with optical fibre uplink. Usually, the Cabinet location has to be upgraded relating space, outside capability, power supply and air-condition. This migration requires a fibre roll-out in the Main Cable section of the Service Area between LEx and Distribution Cabinet. The customers that can be reached by an FTTCab solution and the data rates are limited by the distribution cable length, the copper cabling and the applied DSL technology.

The links between the LEx and Cabinets will be realised on the basis of fibre connections that can be realized by different optical system solutions. Figure 2.5 gives a schematic overview of three FTTCab uplink options.

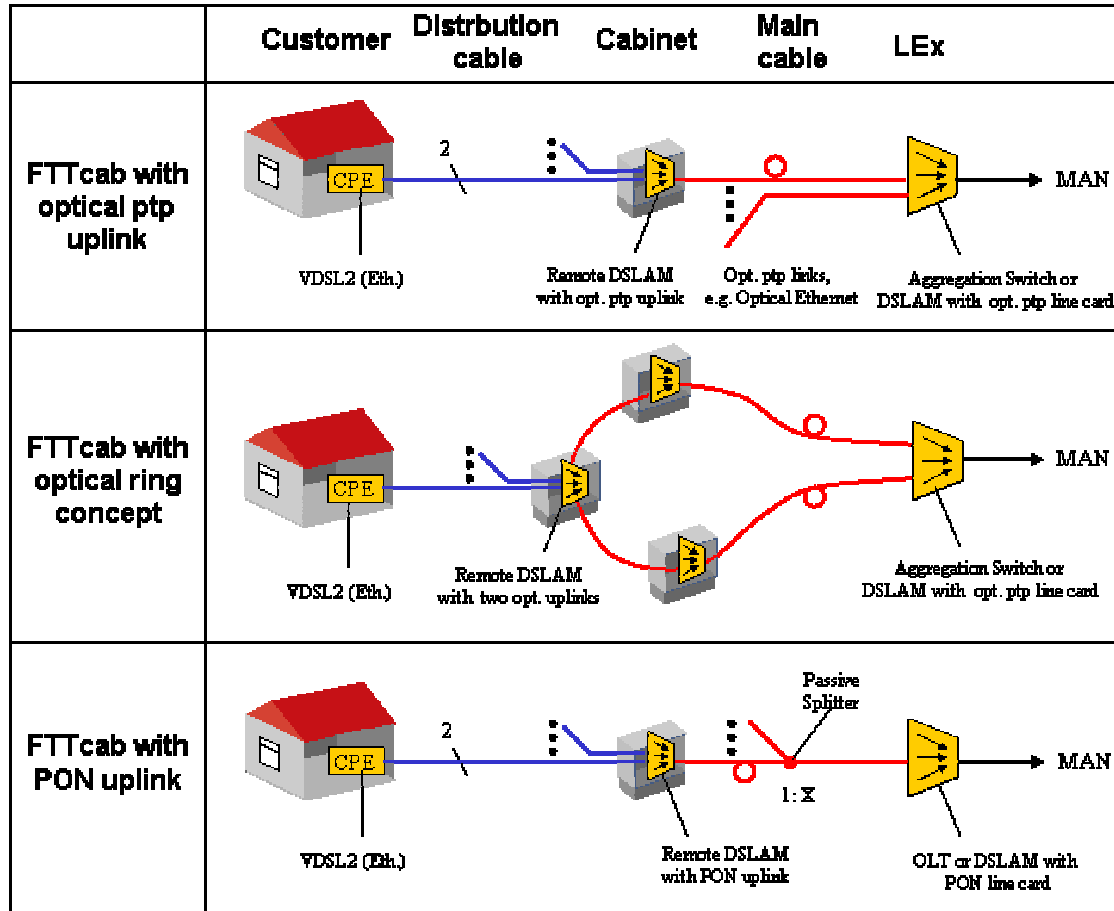


Figure 2.5 FTTCab uplink options

For FTTCab with optical P-t-P uplink, the links between the LEx and Cabinets will be realised by fibre point to point connections. It is the most simple approach, feasible today with proved technology. This solution supposes the use of a lot of fibres due to the fact that we need at least one fibre per each cabinet. It provides the most future safe infrastructure for upgrades in bandwidth capacity. In addition, a lot of line card interfaces are needed at the LEx location.

The Optical Ethernet standards, especially the Ethernet in the First Mile (EFM) specifications can be used for that scenario.

FTTCab with an optical ring concept aims on a fibre ring topology in the Main cable section of the Access Network in order to reduce the needed fibres. The ring bandwidth will be shared by multiple Remote DSLAMs. This solution offers more redundancy, but the complexity of Remote DSLAM increases because a ring routing mechanism and more backplane capacity are required. This solution can also be realised by Optical Ethernet (e.g. Gigabit Ethernet) using the IEEE 802.1 Spanning Tree Protocols (native STP, Rapid spanning tree, Multiple spanning tree Protocol) that generate a logical tree structure on the ring and provide a redundancy mechanism. Rapid spanning tree is able to provide a reconfiguration time less than 1 second. Faster ring reconfiguration (Sub 50 msec) can be realised by the IEEE Layer-2 protocol Resilience Packet Ring (RPR) or other propriety protocols.

In FTTCab with PON uplink scenario the connections between the LEx and the cabinets are implemented with a Passive Optical Network (PON) topology. Figure 2.6 gives an overview of the PON standardization including the bandwidth performance. EPON and GPON are relevant today and allow for high, symmetrical bandwidths suited to feed cabinets.

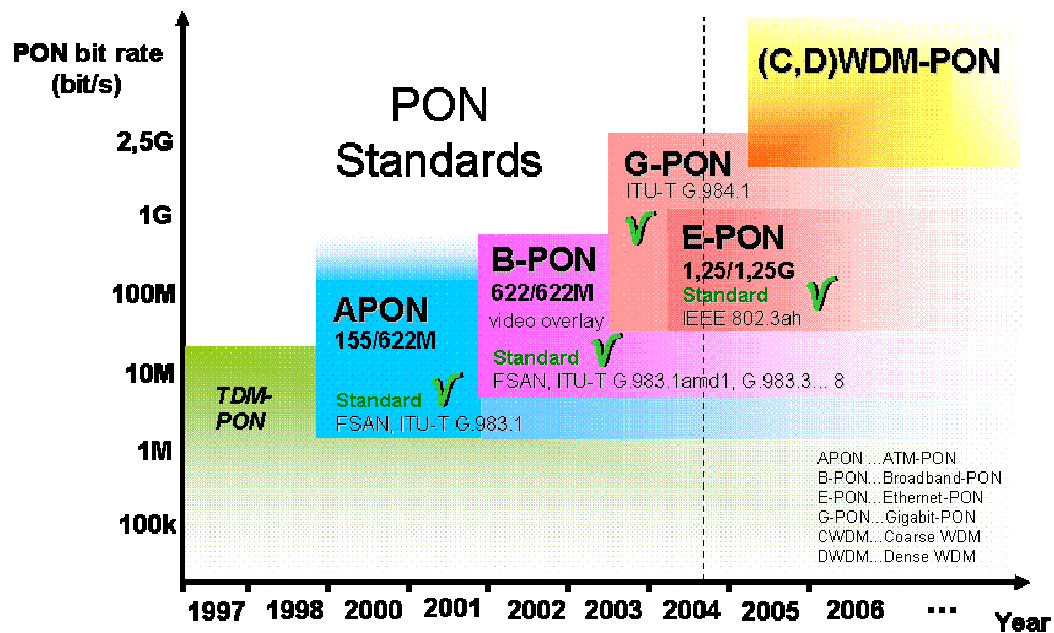


Figure 2.6 Overview of PON standards

A PON consists of an Optical Line Termination (OLT) that feeds multiple Optical Network Units (ONU). PONs do not need active components between OLT and ONUs. Fibres are distributed by passive optical splitters.

In case of FTTCab the OLT is located at the LEx, for example at DSLAM line cards, while the ONU are installed at the cabinets, for example as part of the Remote DSLAM. A PON architectures also reduces the fibre cost for the Main cable section. Additionally, P-t-P and ring concepts require more interfaces at the LEx or Cabinet locations compared to the PON solution. The PON allows for a dynamic management of the bandwidth capacity per cabinet. The number of cabinets per PON can be adjusted to the traffic needs and evolution in a flexible way.

The FTTCab concept enables to reach the majority of customers with very high data rates provided by ADSL2+ or VDSL2.

The number of deployed spare copper-wire in the distribution cable-section is usually higher compared to the main cable-section in order to be flexible in terms of changing customer distribution. So a FTTCab concept offers the chance of a cost efficient feasibility of Bonding mechanisms to realize higher reach and data rates.

There are however also large initial investments for the FTTCab concept due to the high effort for the new optical infrastructure and the usually required upgrade of the existing Cabinet locations regarding outside capability, power supply and air-conditioned environment cause also for the FTTCab concept high initial investments. On the other hand, in urban areas the Main Cable section usually has a large installed duct base that enables a cost optimised fibre roll-out up to the Cabinet. In addition, there are some concepts to keep down the investments for the Cabinet location discussed in the following sections.

2.3.3.1 Mini DSLAM with remote powering

In case of a standard FTTCab approach, usually a new fibre-cabinet is required. In general it has to be deployed beside the existing copper-cabinets which will be equipped with a large ONU and a local power-supply. The main disadvantages of the standard-scenario are related to the beginning of the deployment (first years), these are:

- high initial investments
- local power supply
- copper-interconnections between each new fibre-cabinet and the neighbouring copper-cabinet
- restricted space in the streets/curbs for a second cabinet

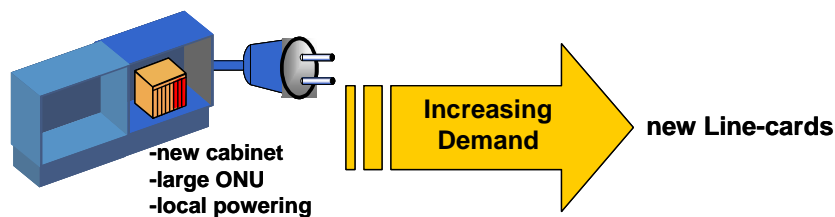


Figure 2.7: FTTCab Standard scenario

FTTCab migration option:

The existing copper-cabinets will be equipped with a small ONU (may be 12-24 DSL lines) that enables the ability to provide remote powering due to the small number of DSL-lines, and thus low power budget. That could help to keep down the initial investments if the customer penetration increases slowly. Powering can be realised on the basis of Remote powering using spare copper pairs of the Main cable or other alternative powering concepts discussed in section 2.3.3.1.1.

The main advantages of the migration-scenario are:

- low initial investments (risk minimization)
- remote powering
- no additional cabinet has to be built up
- all switching works within the same cabinet
- allows a smoothly and cost effective migration towards Fibre to the Building (FTTB)

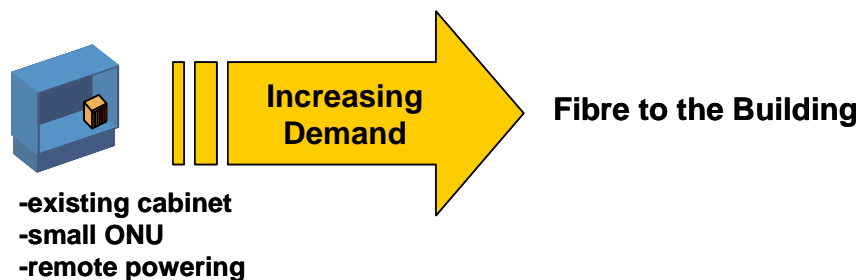


Figure 2.8: FTTCab migration option

The customer penetration is limited due to the small size (conceptional) and remote powering. The data rate is limited by the copper cabling and the applied DSL technology.

2.3.3.1.1 Alternative remote powering concepts

220V Local Powering (Status Quo)

For a FTTCab approach usually each cabinet gets its own 220V power supply that is delivered by a local power provider. This powering upgrade concept causes high initial investments. Following some remote powering concepts are discussed that offer the change to keep down the investments for cabinet powering.

310 V Remote Powering using existing copper pairs

This concept realises remote powering on the basis of 310 V/ 59 mA DC over one or more existing copper pairs between LEx and Outdoor Location (Figure 2.9).

The limit of one copper pair is 17 W but in order to increase the power it is possible to use multiple copper pairs. (Example: 100W; Distance 5000m needs 12 twisted copper pairs)

In general this concept is limited by the number of the available copper pairs and distance between LEx and Outdoor Location. Figure 2.10 shows the reach per number of copper pairs (0.5 mm) to provide 100W, 150W and 200W.

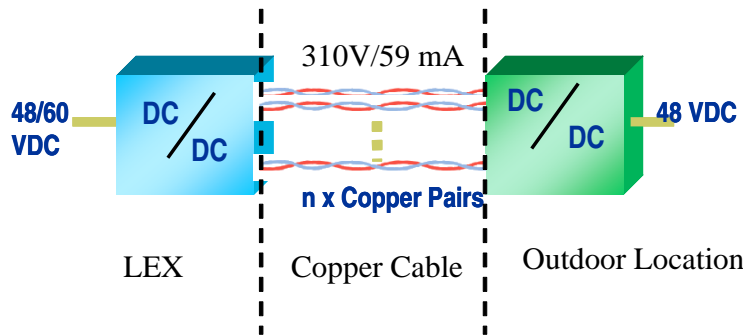


Figure 2.9 310 V Remote Powering

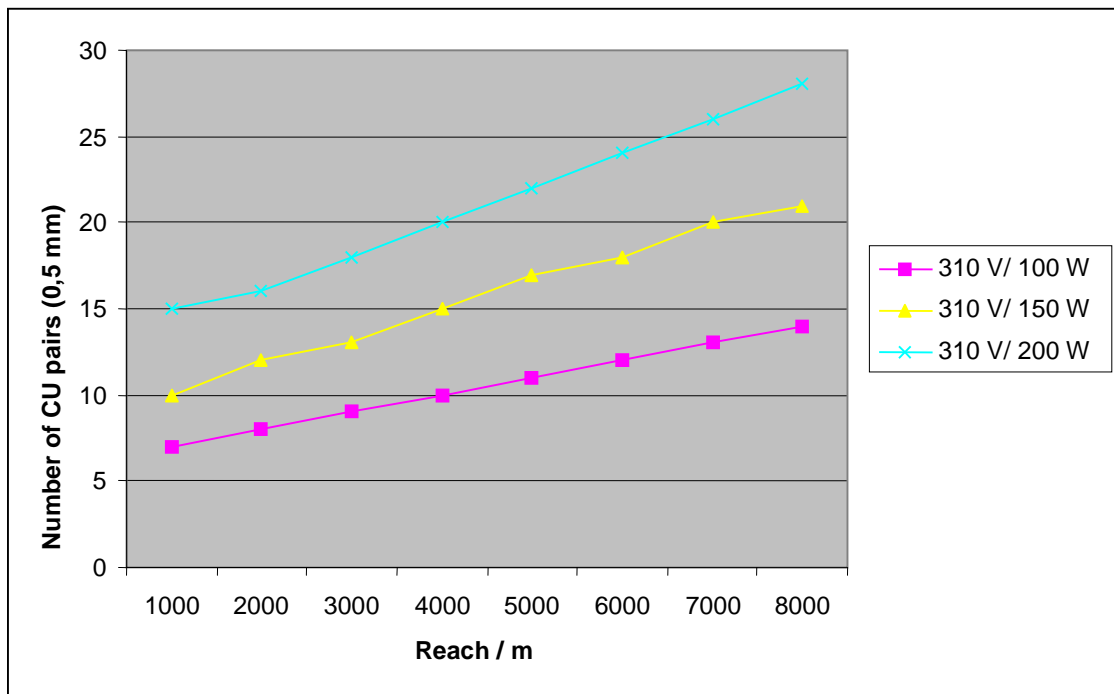


Figure 2.10 310 V Remote Powering: Number of CU pairs versus Reach

110 V Remote Powering using existing copper pairs

In contrast to the concept described before this option provides powering on the basis of 110 V DC over one or more existing copper pairs between LEX and Outdoor Location (Figure 2.11). The max output wattage of one system is limited to 600 W.

Also this concept is limited by the number of the available copper pairs and distance between LEX and Outdoor Location. Figure 2.12 shows the reach per number of copper pairs (0.5 mm) to provide 100W, 150W and 200W. (Example: 100W; Distance 5000m requires 30 copper pairs)

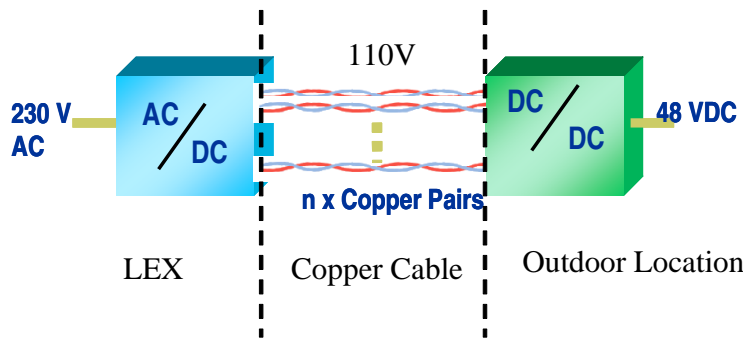


Figure 2.11 110 V Remote Powering

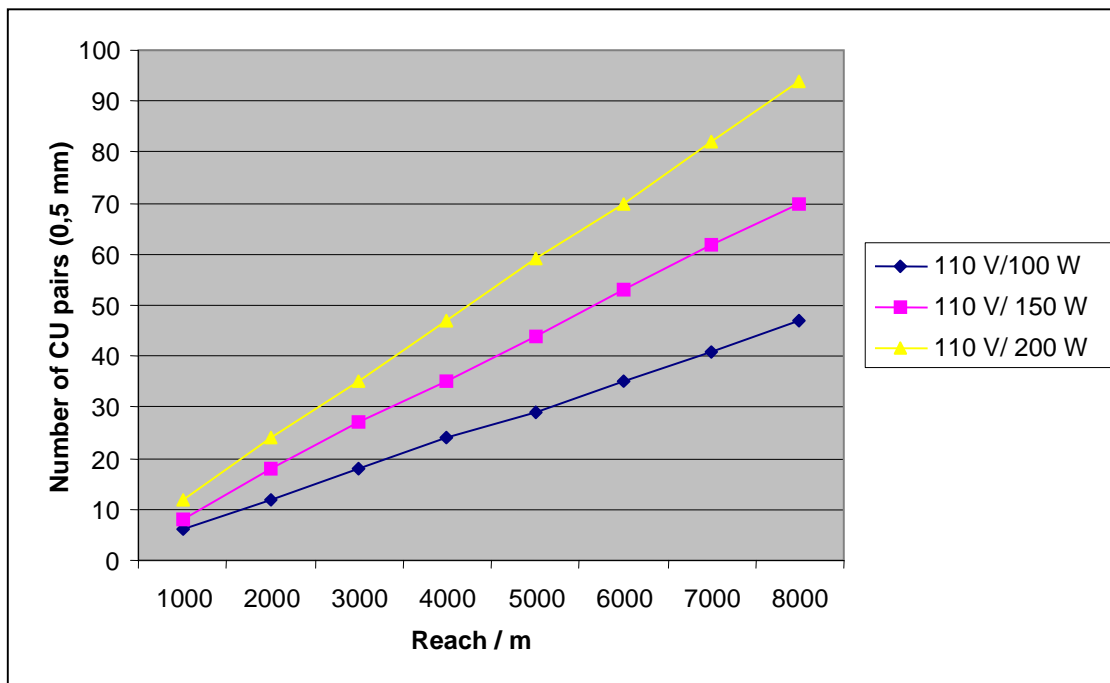


Figure 2.12 110 V Remote Powering: Number of CU pairs versus Reach

Remote powering over power cables using Medium voltage AC powering (1000V)

The Medium voltage AC (1000V) remote powering is a technically feasible and reliable solution especially for powering of multiple cabinets when power cables can be installed in existing infrastructure.

The simplicity and the robustness of the adopted topology was demonstrated and proved by laboratory trials. The EURESCOM P 918 D7 presents the results of a laboratory tests in detail.

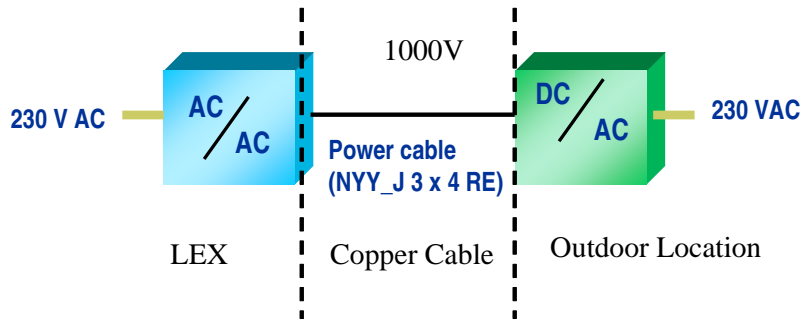


Figure 2.13 Remote powering over power cables using Medium voltage AC powering (1000V)

Remote powering over power cables using 110V DC

An optional solution for remote powering using power cables can be realised on the basis of 110V DC/600W (max voltage 118 V- DC) powering (Figure 2.14).

Figure 2.15 shows the possible Output wattage and reach for a power cable with cross-sectional area of 2,5 mm² and 118 V DC with impedance matching.

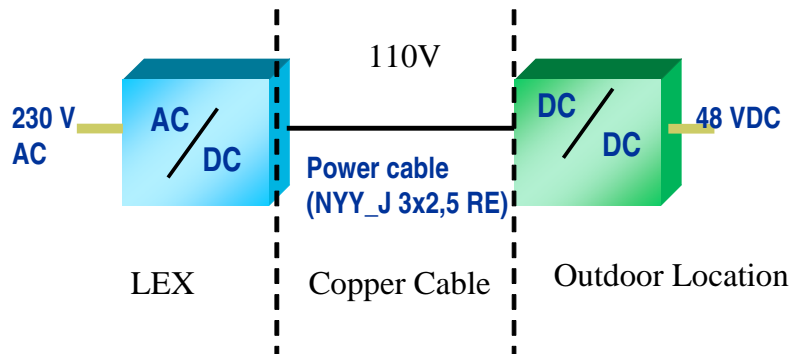


Figure 2.14 Remote powering over power cables using 110V DC

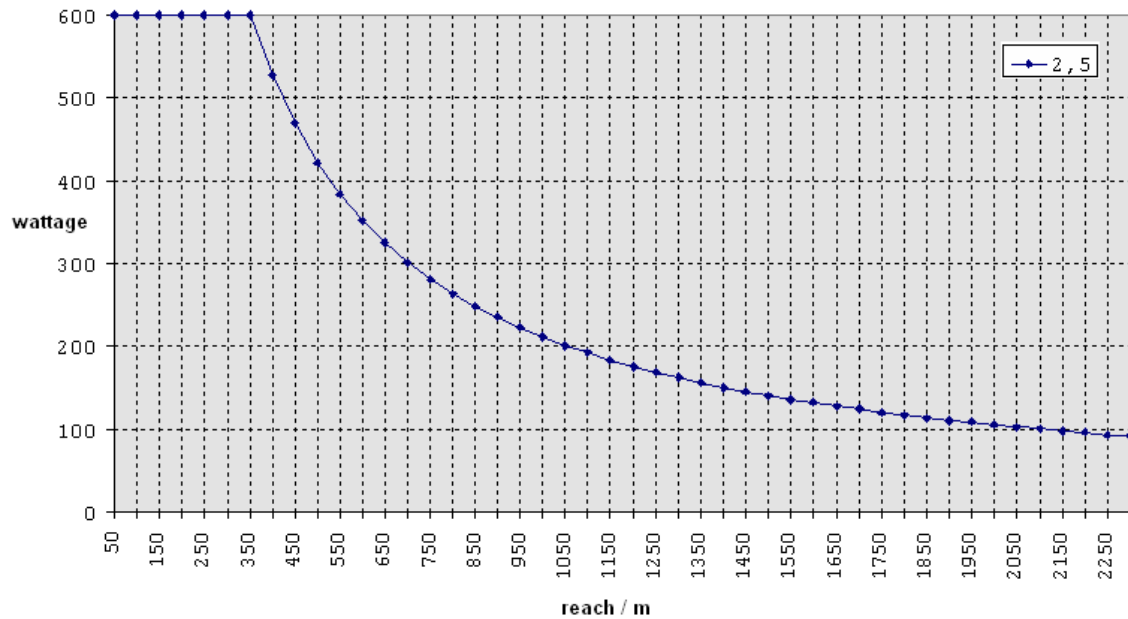


Figure 2.15 Remote powering over power cables using 110V DC: Watt

Cluster Powering

This concept is a combination of 220V Local Powering and remote powering. The idea is to create Powering clusters (Figure 2.17) on the basis of Master cabinets (220V local powering) that feed Slave cabinets using remote powering techniques. Only some of the cabinets of a Service Area must be updated with local powering.

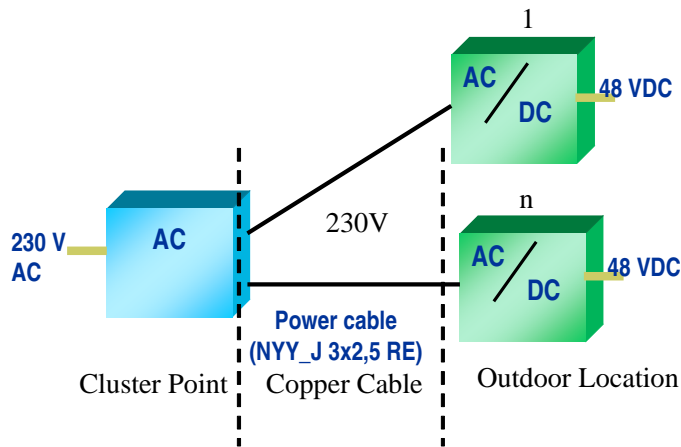


Figure 2.16 Cluster Powering



Figure 2.17 Powering clusters

Powering from customer network side

This solution is based on a new way of thinking. Usually the cabinet outdoor equipment is provided with power from the Operator's side. An option is the powering of new locations over customer equipment (e. g. NT powers the Line Termination card) or a separate power unit at the customer location.

The Operator using this concept has to consider following challenges:

- Customer change
- Location lost
- Monitoring
- Settlement of power consumption

2.3.3.2 Central cabinet migration concept with local powering

The introduction of a central cabinet beside an existing copper-cabinet which feeds more than one other copper-cabinets could be a cost effective migration concept, in order to avoid the high initial investments for a fibre roll-out including the fibre cable infrastructure and the building up of new housings with powering. The cabinets within the same cluster must be connected at the same main-cable. The number of cabinets which can be fed from the central fibre cabinet depends on the cable length distribution of the respective service access area. Another limitation is the restricted space for connections within the existing copper-cabinet (central copper-cabinet) beside the new fibre cabinet. Therefore, in total no more than 4 copper-cabinets should be clustered. The central copper-cabinet has to be connected with a new copper-cable, in order to interconnect with the other copper-cabinets. The new copper-cable can be laid within the new fibre-cable route. All copper-pairs within a cabinet-cluster should be prepared and connected through already at the beginning in order to avoid increasing costs for step-by-step switching works and operations. Figure 2.18 shows the central cabinet concept for example with 2 and 3, respectively, copper-cabinets per cluster. The central cabinet concept will be used within the standard-scenario described in the section above.

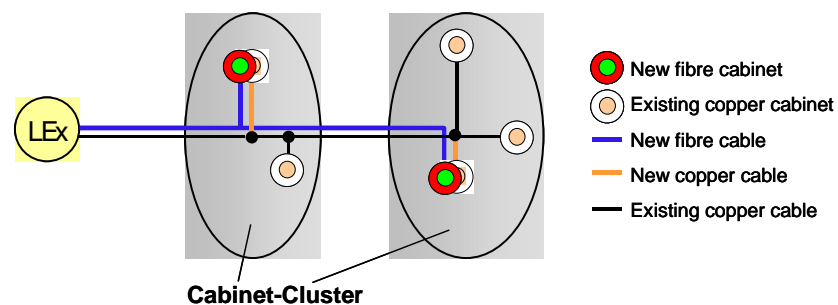


Figure 2.18: Central cabinet concept

The customer penetration limit depends on the number of available pairs of the new copper cabling to other Cabinets. The data rate is limited by the additional copper cabling and the applied DSL technology.

2.3.3.3 xDSL over optics

xDSL over optics is a concept that is discussed in MUSE Sub-project D (DD2.1 First Mile Options). It means a transport system between DSLAM and remote node (e.g. at Distribution Cabinet) that offers the possibility to reduce the complexity and power consumption of the remote node that works as a simple De-/Multiplexer without additional signal processing usually provided by a DSLAM (see Figure 2.19). The DSLAM functionality is limited on the Local Exchange location.

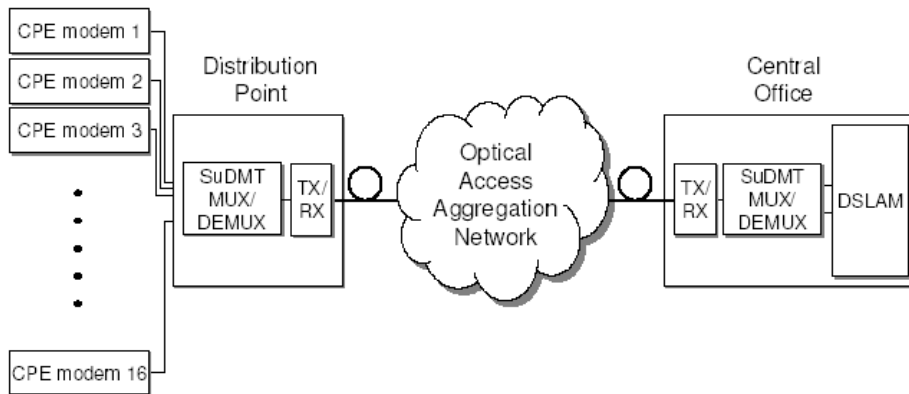


Figure 2.19 xDSL over optics

This concept is qualified for the basic FTTCab approach that requires an upgrade of the Cabinet location regarding footprint, air-condition and power supply, but as well as the “Mini” DSLAM discussed in section 2.3.3.1 a small Remote node device providing 10 to 12 DSL lines is qualified for a remote powering set-up due to its low power budget.

However, xDSL over optics offers the chance to reduce the FTTCab roll-out compared to a solution using Remote DSLAMs.

2.3.4 FTTB migration

Fibre To The Building (FTTB) could become necessary if the high bandwidth capabilities of advanced DSL-technologies from the cabinet/curb (e.g. VDSL2) is not sufficient. In these cases a FTTB DSLAM with optical uplink can be installed inside of buildings, e.g. in the basement. The powering of the Building DSLAM should be separated and not accessible for the dweller, in order to avoid intended or inadvertent disabling. For in-house wiring today mainly quadruple bundles with twisted copper-pairs (usually Cat.3) are used in contrast to the today’s first mile outside plants where usually quadruple bundles with un-twisted copper-pairs are deployed. The twisting of pairs improves the crosstalk conditions, compared to the un-twisted pairs. Hence, the limits of FTTB will in general not be caused by the in-house wiring but rather by the high bandwidth limitations of advanced DSL-technologies with up to 100 Mbit/s.

In general a FTTB concept is more expensive than a FTTCab approach but it can be an economical solution especially for multi dwelling buildings or office buildings and Greenfield situations.

2.3.5 Migration path options

This section discusses two DSL migration paths depicted in Figure 2.20.

- Path 1 (Main Path) - CAPEX minimised, low risk migration
- Path 2 - “Shortcut” to FTTB migration

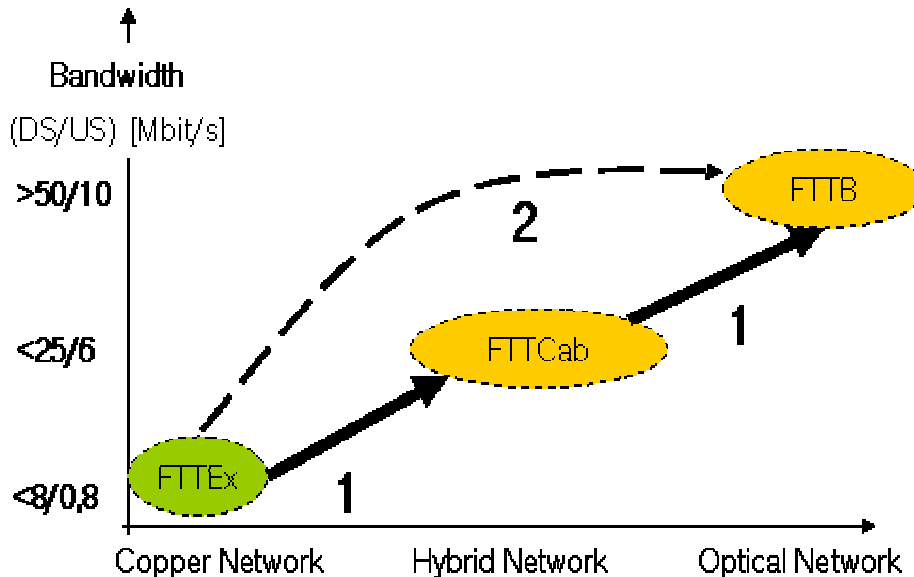


Figure 2.20 Migration path options

Path 1 (Main Path) - CAPEX minimised, low risk migration

Migration Path 1 aims at a mass market roll out and minimises the economical risk in case the customer penetration slowly increases. Path 1 starts with a FTTE_x approach. Around the Local Exchange all customers which can be reached by a specific high rate DSL technique will be connected without any infrastructure workings. Especially in urban areas a considerable number of customers can be connected on the basis of ADSL2+ or VDSL2. In the next step a FTTCab roll-out is usually the most efficient solution for the Mass market.

Additionally, concepts to keep down the investments for the Cabinet location must be considered, e.g. Mini DSLAM with remote powering, Central cabinet migration concept with local powering and VDSL over optics. In the last step, a gradual connection of buildings towards FTTB is possible depending on bandwidth demand per customer. A DSLAM with optical uplink can be installed inside of buildings, e.g. in the basement. In general a FTTB concept is more expensive than a FTTCab approach but it can be an economical solution especially for multi dwelling buildings or office buildings and Greenfield situations.

Path 2 - “Shortcut” to FTTB migration

Migration Path 2 is an option for service offerings with data rates higher than 25 Mbit/s that requires more and more an FTTB approach. On the other hand it is the most suited solution for deployments in selected areas with powerful duct (fibre) infrastructure (dense urban, urban areas), where FTTB becomes cost competitive to FTTCab, where it is not possible to install new street cabinets, where or alternatives are too expensive, or in areas with high competition (strategic positioning).

3 DSL PHYSICAL LAYER EVOLUTION

This chapter discusses migration aspects of different xDSL technologies.

3.1 Migration path to ADSL2

The following sections show technical impacts on the network elements and roadmaps to introduce ADSL2.

3.1.1 Motivation for Migration to ADSL2

ADSL grew over many years to a world-wide distributed technology. Particularly mass market services are focussed by ADSL and are the drivers for the enormous increase of DSL lines. In this context, a small reduction in OPEX for each line deployed can lead to a huge reduction in OPEX for the network operator considering the whole network.

ADSL2, as specified by ITU-T G.992.3, includes a lot of new and advanced features that provide means to reduce operational expenses. It should be noted that ADSL2 will only partially enable new types of services. But mainly enhancements for improved, more stable and reliable operation will be the motivation to migrate from ADSL to ADSL2.

The main features of ADSL2 are:

- Backward compatibility to ADSL
- Power down capabilities: offer a high potential to reduce power consumption and heat dissipation in FTTE_x and FTTC_{ab} installations; enable increased port density per DSLAM
- Improved performance (rate, reach): however not a significant step forward, neither in reach nor in bit-rate
- More robustness, particularly against narrowband interferers
- Enhanced power cut back capabilities can reduce spectral impact on adjacent systems in the same cable bundle
- Spectral Shaping: ADSL2 offers means to optimise network individually transmit spectra
- Improved seamless rate adaptation during operation, depending on receiver SNR
- Improved support for voice transmission, especially for Channelised Voice over ADSL (CVoDSL)
- Improved All Digital Mode of operation (ADM)
- Support for IMA
- Enhanced diagnostic means: noise, attenuation, SNR, optional using a dedicated diagnostics mode even when successful training will not work
- Carrier blackout possibilities to enable e.g. RFI cancellation

3.1.2 Migration aspects

A migration to ADSL2 should influence the provisioning process only in a minor way. That is, given a running ADSL installation base a smooth migration to ADSL2 should be possible without major obstacles. The following migration aspects are to be considered:

The mode of ADSL (Annexes)

Every Network Operator has to choose between several Annexes from the ITU-T G.992.3 standard serving different needs. All these Annexes represent ADSL variants which may or may not be spectral compatible to be deployed in the same cable or together with other DSL lines. Also, it cannot be expected that there is full interoperability between all these Annexes (CPA and DSLAM). This is valid for ADSL as well.

Proven backward compatibility to ADSL

This migration scenario supposes that both directions – the DSLAM interface (ATU-C) and the CPE interface (ATU-R) will be compatible between ADSL and ADSL2. It is up to the Network Operator to decide what will be the first interface providing ADSL2, but the current installation base should work further on.

Availability of chipsets

The roadmap for introducing ADSL2 depends on the availability of ADSL2 transceivers and the system/CPE integration. It is expected that the CO side will first support ADSL2 but to take advantage of all provided features ADSL2 must also be supported from the CPE side.

Determination of additional operational parameters for the new features

Particularly for sensitive features like spectral shaping or power down timing a new set of parameters has to be fixed. This might take resources for testing and might influence existing services. The Network Operator should be aware of that.

Extension of the element management in order to address the relevant new features

ADSL2 will provide many new MIB elements. The migration to ADSL2 will cause an update of the element management when the Network Operator will use the same ADSL optimized management platform.

Establishing requirements for interoperability, Interop test plans and beds

Interoperability between DSLAM and CPE became a key factor for an ADSL installation and this will remain for ADSL2. ADSL2 comes with many new features and claims to improve interoperability. It is vital to enhance the test procedures, test specifications and test beds for ADSL2 to include all new aspects. DSL Forum already decided to work out an interoperability test plan with important contributions from MUSE (see new created DSL Forum Working Text WT-100).

Check for possible changes in provisioning process

ADSL2 from a first view should not necessarily influence established provisioning processes. But some aspects may cause changes:

- Co-existence of ADSL and ADSL2 network elements may lead to logistic enhancements, especially in connection to new services only available with ADSL2

- The parameter determination and element management updates may impact the provisioning process as well
- New services could be created on the base of new ADSL2 features – This might cause even totally new provisioning processes

3.1.3 Summary

A migration to ADSL2 is motivated by some new features. The main driver will be the reduction of operational costs, but ADSL2 also offers new or advanced services.

Major migration aspects are the co-existence to ADSL, backwards compatibility and addressing of necessary changes in the network, e.g. the element management. Interoperability will remain an important issue for ADSL2 which leads to new tests and test facilities.

3.2 Migration path to ADSL2+

This section shows technical impacts on the network elements and roadmaps to introduce ADSL2+.

3.2.1 Motivation for migration to ADSL2+

ADSL2+ is a DSL technology that increases the improvements obtained in ADSL2. It is specified on the ITU-T recommendation G.922.5.

Similar to ADSL2, in the European market, there are different operation modes depending on the spectral upstream assignation that regulate the rates reached in each mode.

An important improvement is the fact that ADSL2+ supplies the ability to duplicate the range of frequencies used until now, reaching up to 2.2 MHz on the bandwidth.

This expansion in the bandwidth means:

- An increase in the data rates. It can be found the next annexes in the recommendation:
 - Annexe A: upstream of 0.8 Mbps and downstream up to 24 Mbps.
 - Annexe L: upstream of 2.5 Mbps and downstream up to 20 Mbps.
 - Annexe J: upstream of 2.5 Mbps and downstream up to 20 Mbps.

The difference between Annexe L and Annexe J is that in the L Annexe POTS is permitted inside the 0-25 KHz band, as it can be seen in Figure 3-1.

- A reduction of interferences that take place in the loop. This is due to the capability to use only tones between 1.1 – 2.2 MHz.

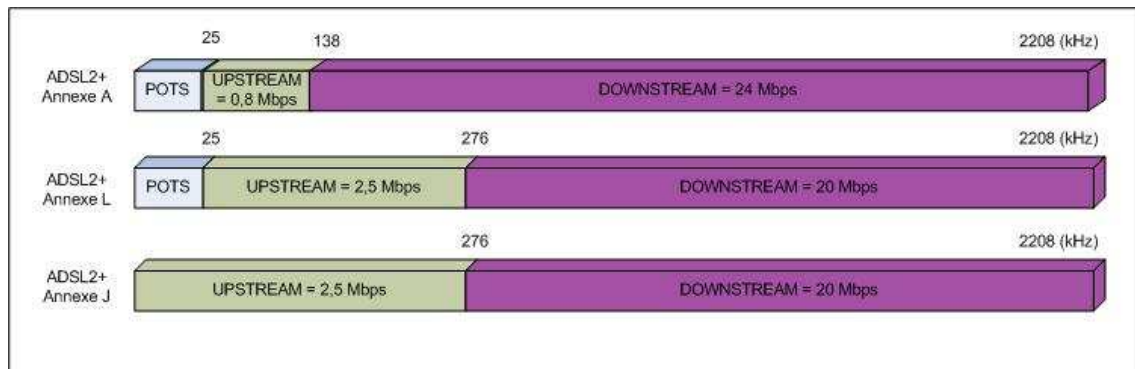


Figure 3.1: Analysis of the bandwidth.

ADSL2+ shows its versatility improving the relationship between reach and capability more than VDSL, SHDSL and ADSL technologies do.

Other very important characteristics are:

- A fast start that only requires 3 seconds against the 10 seconds wasted in ADSL.
- Spectral channelling, which allows a better use of the spectrum according to the kind of application, that is, the spectrum can be divided, keeping a portion for circuit switching (voice, ISDN, etc.), another one for data (Internet), etc.
- An efficient energy management, including low consumption modes, stand-by, etc.

3.2.2 Migration aspects

All the migration aspects considered before in ADSL2, such as: the ADSL mode, the proven backward compatibility to ADSL, the availability of chipset, the additional operational parameters, the extension of the element management, the requirements for interoperability and the check for possible changes in provisioning process must be considered here too.

From the point of view of network providers the manufacturers only will have to update the equipment's firmware at both sides of the loop to implant this technology. However, a standardisation will be required in order to maintain the interoperability, as performed by MUSE in DSL Forum, working group Test & Interoperability.

There exist a lot of fabricants that have developed interfaces compatibles with ADSL, ADSL2 and ADSL2+ technologies. This will permit to maintain the backward compatibility to ADSL and ADSL2.

3.2.3 Summary

The main driver will be the duplicate of frequency ranges which will increase the data rates and the reduction of interferences in the loop. Moreover, all those drivers obtained before in the ADSL2 are also main drivers here, because it must be remembered that ADSL2+ is based on ADSL2, getting the best from it and improving it to supply new features as fast start, spectral channelling and an efficient energy management including modes of low consume, stand-by, etc.

3.3 Migration path to VDSL and VDSL2

Beginning from an identification of the VDSL and VDSL2 variants a guideline for the introduction distinguished for different scenarios should be given. This could also include EMC and regulatory issues.

3.3.1 VDSL History

The development of VDSL began in laboratories in about 1990. Initially with the idea of fibre distribution to a distribution point close to the customer: either at the pole-top, or in an underground 'Footway Box'. This scenario later became known as FTTC or 'Fibre to the Curb'. Initially the hope was to use a very simple line code, but performance and EMC considerations undermined this assumption and the opportunities for VDSL like deployment were abandoned in favour of exchange based ADSL service concepts.

A second attempt to define a VDSL like system was initiated by DAVIC in the mid 1990's. Their FTTC system was based on CAP technology pioneered for HDSL in North America. This approach was again based on a FTTC service scenario, and included to the concept of in-premises distribution over TV coaxial distribution cables.

Also in the mid 1990's there was a proposal to define a short reach high rate derivative of ADSL. There was some dispute about what this should be named, Work started in North America and Europe on the definition of VDSL.

3.3.2 VDSL Standards

From an early stage the work on VDSL standards was threatened by dispute about which line code should be used. This carried over from previous disputes about ADSL and RADSL.

ETSI and T1E1 started work capturing VDSL requirements. In this activity attention focussed on VDSL from the cabinet FTTCab as the most likely deployment, though Exchange (Central Office) deployment was also envisaged. PSD limits were developed suitable for both applications. These requirements also included consideration for EMC aspects - allowing for lower PSD limits for use on exposed (overhead) wires, and for notches to protect nearby amateur radio receivers, and to protect VDSL from amateur radio transmissions.

Considerations of the cross talk environment inevitably led to selection of Frequency Domain Duplex operation, and to the need to define bandplans suitable for different network requirements. The FSAN network operators developed proposals for asymmetric (video centric) and symmetric (data centric) bandplans with different upstream-downstream frequency allocations - plan 997 and 998 respectively.

This work was embodied in the first ETSI TS 101 270-1 "Very high speed Digital Subscriber Line (VDSL), Part 1: Functional requirements" (1998). This did not specify a line code. The debate on line code was initiated in the ITU, but ETSI produced a dual line code standard TS 101 270-1 (2003) "Very High Speed Digital Subscriber Line (VDSL); Part 2: Transceiver" specification. This specification included both DMT and QAM line code solutions. The ITU finally decided that future work would be on a new DMT based VDSL standard called VDSL2. This decision was based on a short-term agreement on a dual line code recommendation G.993.1.

3.3.3 VDSL from the Cabinet

In this scenario VDSL line terminations are hosted at a flexibility point in the network that typically serve in the order of 300 homes. The purpose of these flexibility points is to accommodate customer churn, providing a 'patch panel' facility to link fixed customer dedicated drop wires to available links back to the exchange. Usually these points are implemented as street cabinets, though in the case of large buildings various kinds of wire termination and cross connect may be found in public space or in special wiring closets.

The size and location of cabinets varies across Europe. Similarly the length of customer side sub-loops varies between countries, and with geotype (rural, suburban, dense urban etc). Also cables vary quite widely.

It is often useful to consider the customer side sub-loop in two parts: a multi-pair distribution wire and a final drop wire. The distribution wires tend to fall into two categories: quad based (e.g. Germany) and pair based (e.g. UK). Quad based cables generally have higher characteristic impedance (circa 135 ohms) than pair-based cables that have characteristic impedance near 100 ohms. This has an important effect on high frequency loss, since the same wire gauge exhibits lower loss with higher impedance. Taking into account geographical demographic factors, there is a wider variation in the average electrical length between and within countries: say 300m to 600m.

Final drop wires are more variable. In each country there are a range of legacy deployment practices represented. This could range from 180 Ohm low loss untwisted aerial drop wire with thick insulation, to silk covered low impedance wires in old buildings. The length of these wires is not a significant proportion of the overall sub-loop length, but they can give rise to cause strong reflections that cause pulse dispersion. Also the crosstalk behaviour of wiring in multiple tenancy units is uncontrolled and unpredictable.

Another feature of the final drop is susceptibility to radio frequency noise ingress. At low frequencies (e.g. long wave) underground cables can pick up strong common mode components that can be converted to differential mode at points unbalance in the final drop section. However over most of the VDSL band there is likely to be quite strong ingress of radio frequency broadcast signals. In fact, the overhead section of an aerial final drop is likely to be resonant (and a good antenna) at some frequency in the VDSL band.

There is also variation in maximum length. In the UK for instance there may be sub-loops of up to 2.5 km. This leads to the requirement that VDSL must address a very wide range of rate-reach combinations, stretching from 1 Mbit/s rates (like in ADSL) up to 50 Mb/s on shorter loops. Another feature of the UK in particular is that far-end cross talk in British cables has been found to be 5 dB higher than is the norm in Europe.

A critical feature of VDSL from the cabinet is that some loops will be carrying ADSL from the exchange. It was foreseen in the original VDSL bandplans that this would be accommodated by the frequency separation of ADSL downstream signals and VDSL signals, with a split in the region of 1 MHz. VDSL PSD masks were defined specifically to permit this mode of operation. However, the arrival of ADSL2+ has undermined these assumptions. The VDSL bandplans defined for cabinet location would severely impact ADSL2+ from the exchange deployment.

In some countries with short low-loss loops there may be scope to sacrifice the band up to 2.2 MHz to ADSL2+ from the exchange, though the loss of capacity could amount to 5 to 10 Mbit/s. In other countries, such as the UK, with long loops and high crosstalk cable, the loss of capacity would be catastrophic for VDSL deployment.

3.3.4 VDSL from the exchange

In some networks, most customers are served from cabinets, and this makes VDSL from the cabinet the preferred means to reach those customers. VDSL deployment in the cabinet would prevent simultaneous VDSL deployment in the exchange over the same cable plant using the same power spectrum and band plan. This is because downstream signals injected at the cabinet will be much stronger in the final section of cable than signals in adjacent pairs injected at the exchange. This has the consequence that the FEXT caused by cabinet systems will tend to drown the weak signals arriving from the exchange. This effect is known as the near-far problem.

However, in some networks, cabinets are not used to serve all customers. In some small exchanges may connect all the customers may be connected directly by small multi-pair cables to a single flexibility points (or distribution points) close the customer. In these configurations there is no impediment to deployment of VDSL in the exchange. The same is true for some exchanges in dense urban areas where the loop lengths and short, and cable topology does not require cabinets.

A challenge in VDSL from the exchange is the need to use ADSL PSD limits at low frequencies while extending the band plan to 12 MHz and beyond. The problem is that the maximum power required for ADSL (100 mW), is difficult to achieve simultaneously with the high bandwidth.

3.3.5 VDSL from the DP (FTTC or FTTBuilding)

VDSL may be deployed from distribution points close to the customer (typically on less than 200m sub-loops). There are three drivers for this approach. One is to serve customers in a multi-tenanted building from a secure benign low-cost location; another is to reach customers that are too far from a cabinet to receive a high rate ubiquitous service; as an enabler for fibre to the home. DP deployment retains the benefit of avoiding the high costs associated with getting fibre across the last 100m to the home.

In some networks the technology may be used to provide higher service capacity than is possible on the longer loops from the cabinet. However, the same crosstalk problem arises as afflicts the VDSL from the cabinet and ADSL2+ from the exchange debate. In a Local Loop Unbundling (LLU) environment it is probably necessary to provide some segregation between bands used for FTTCab and FTTC.

In some ways the technology for FTTC can be borrowed from the cabinet location. However, remote devices for these locations represent considerable challenge in terms of complexity and power requirements. They may need to be located in small robust enclosures and with minimum technician attention. Special attention needs to be given to the management and control plane complexity, and each needs to be scaled appropriately. However, the low intervention paradigm may require powerful loop maintenance capabilities, and leads on to the possibility of ubiquitous provision for zero touch management. These aspects will be addressed in more detail in MUSE phase II,

3.3.6 VDSL Deployment in Europe

The mutual incompatibility of VDSL from the cabinet, and ADSL2+ from the exchange has raised significant problems in regulation across Europe. The desire of incumbent operators to plan for VDSL deployment from the cabinet is increasingly under threat from other operators seeking to exploit LLU to serve a small customer base from the exchange. Even incumbent operators find it difficult to balance the immediate benefits of exchange ADSL2+ deployment against the future prospect of ubiquitous VDSL deployment from the cabinet. This divergence of interest leads to disputes in the development agreement and maintenance of regulatory settlements. In particular disputes regarding whether the rules should be changed favour a new service offering from the exchange at the expense of future service benefits from remote nodes.

The future of MUSE as a ubiquitous solution also depends on VDSL. Unless technical solutions emerge that enable a regulatory compromise, the future of MUSE high bandwidth services is questionable.

The most notable deployment of VDSL in Europe has just started in Belgium using VDSL1. A key feature in migration is that the CPE (Network Terminating Equipment NTE) remains under the control of the operator. In this event, the customer's terminals have open interfaces, and the VDSL transmission standard is hidden in the NTE. If this approach is sustained then a future migration to VDSL2 will be possible - if inconvenient operationally. However, the cost profile of volume VDSL2 manufacture is likely to make the transition attractive.

For other operators it remains to be seen if there is a business case for large scale deployment before the arrival of VDSL2 equipment.

3.3.7 VDSL2 Issues

The VDSL2 standard, G.993.2, was 'consented' by the ITU-T on May 27, 2005 and sent to the fast track 'Alternative Approval Process' or AAP. At the time of writing it is in the final stage of final call comment resolution, and it is expected that it will pass through the final review comment phase and reach formal approval by the time of the February 2006 ITU Study Group 15 plenary.

VDSL2 is based on DMT. An initial objective was that VDSL2 would be based on convergence of DMT VDSL1 and ADSL2+. The basic symbol structure is the same as ADSL and DMT VDSL1, with a symbol rate of 4 x 69/68 kHz.

An important issue has been meeting long range requirements from North America and the UK in particular. VDSL1 was not optimised for long reach and the use of low frequencies where pulse dispersion is high. The 'cyclic extension' of DMT enables modest pulse dispersion to be accommodated, and the use of entirely highly efficient frequency domain equalisation. However, it has been observed that on long loops and at frequencies essential for obtaining good capacity on them, the pulse dispersion is such that the standard cyclic extension is exhausted. This means that a time domain equaliser (TEQ) and echo canceller (DEC) is justified, as is the case in ADSL.

Consequently it has been agreed that unlike VDSL1, VDSL2 will incorporate TEQ and DEC capabilities for use at low frequencies on longer lines. An alternative approach was proposed, based on halving the symbol rate - to effectively double the length of the cyclic prefix. It was found to improve the long reach capabilities of DMT VDSL without a TEQ, but insufficiently to meet the long reach requirements, and at the expense of extra latency. This extends reach to approximately 1.8 km.

It has been agreed that the benefits of Trellis Coding should be inherited from ADSL2 to provide extra reach. The ITU is also considering the use of advanced coding methods such as Turbo Codes and LDPC. However, in the light of the urgency applied from North American operators it seems unlikely that such methods will find a place in the new recommendation. This is reasonable, particularly in the light of the uncertainty about the behaviour of these line codes in the presence of Repetitive Electrical Impulse Noise (REIN) and other realistic fluctuating noise sources.

Impulse noise protection is another area of continuing debate, following on from discussions on the same topic for ADSL2 and ADSL2+. It is likely that VDSL will prove no less at risk from fluctuating noise than ADSL, and more susceptible to short wave radio frequency ingress and REIN from various domestic and industrial sources.

The range of impulse noise-types that may be met in the field tend to drive the adoption of Dynamic Line-Code Management (DLCM) techniques. However, it is hard to find compromise line-code stings that will meet all service requirements for latency. On lines dominated by irregular and sometimes long impulse noise events the ideal is to have high FEC interleaving latency - perhaps as high as 40 to 80 ms. On lines subject to REIN the ideal is to have either 8+ or 16+ ms interleaving. This encompasses one or two erasure events at 100 Hz. This is fine for some data applications, and video services, but for delay sensitive services - and voice based TDM business services in particular, this may be much too long. In fact the ability to set the FEC parameters to 50% overhead and 1 ms latency for delay sensitive services is an emerging requirement.

The difficulty in arriving a suitable performance-latency trade off acceptable in multi-service VDSL applications raises the issue of how many different latency paths (and performance trade-offs) are required. Compared to VDSL1, VDSL2 will have more flexibility, requiring at least two latency paths, each with a programmable interleaver and its own FEC parameters.

Proposals for a compromise arising in MUSE for a single 'compromise' latency path will be supported by the new recommendation, but it is not clear that this will be sufficient for operators, even though it is from an architectural point of view highly desirable.

Supporting dual latency for instance has never been a feature of ADSL networks, even though the option is part of the standard. A major issue for dual latency is the need to partition available bandwidth between the two paths. It is inefficient to have a fixed partitioning, but the real time signalling required for dynamic traffic dependent re-partitioning (DRR) is an overhead on session based signalling, and a factor that needs to be considered in network management. ATM DRR was investigated in the DSL Forum, but similar work has not been done for Ethernet. There is no support in MUSE architecture for dual latency VDSL bearers. France Telecom and Belgacom strongly supported making dual latency a mandatory requirement for VDSL2 in the ITU recommendation, though the consented document retains an optional status for the second latency path. This issue is likely to be re-addressed in the first revision to the recommendation.

Both ATM and Ethernet Transport Protocol Specific Transmission Convergence Sub-layer specifications will be inherited from VDSL1. However, the Ethernet TPS-TC will be aligned with IEEE practice and incorporate pre-emptive packet transmission based on priority. The implications of such a mechanism have been studied in DTF3.2 section 10.3.4 "Assuring QoS over the 1st Mile bottleneck". The embedded excel program allows to calculate the maximum number of allowed flows. The demand for low latency modes is also driving the development of TDM TPS-TC capabilities. Pair bonding is likely to use G.bond techniques for ATM and Ethernet.

Two other key requirements on VDSL2 are that a common platform should support both VDSL2, ADSL2, and ADSL2+.

The new VDSL2 standard offers, compared to VDSL1, several new features:

- Higher bit-rates
 - Up to 100 Mbit/s symmetric data rates
- ADSL-like long reach (LR) performance
 - Echo Cancellation and Time Domain Equalization to reach required performance for medium and long loop applications up to 1.8 km
- QoS for delay-critical applications
 - The Pre-emption mechanism gives higher priority to the delay-critical voice and video packets over other data packets such as email messages, web-pages etc.
- Handling of different data rates
 - Dual latency (two independent latency paths - option)
 - Dual interleaving (better noise protection and higher security)

Table 3.1 Comparison of VDSL1 and VDSL2

	VDSL1	VDSL2	VDSL2 Benefit
Bandwidth	12MHz	30MHz	Enables 100MBit/s applications with maximum reach Interleaving Triangular Convolutional General Convolutional EOC, Management Register based EOC Message based
Trellis/Viterbi Coding	n.a.	Mandatory	Higher Rate/Reach Performance
LR-VDSL	optional	Mandatory	Reach up to 1.8 km

DSL backwards compatibility	n.a.	Yes - by implementation of ADSL standards in the same platform	VDSL2 Common approaches facilitate ADSL modes being implemented on the same platform.
Downstream linepower	14.5dBm	20dBm	Maximum performance with co-located ADSL / same binder, ADSL/2/2+ compliance
Interleaving	Triangular Convolutional	General Convolutional	Precise and seamless selection of Impulse-noise protection
EOC, Management	Register based EOC	Message	Powerful far-end management, unified OAM model like ADSL2
On-Line Reconfiguration	n.a.	SRA, DRR	Most efficient spectrum usage, based on application needs
Diagnostic Mode	n.a.	Yes	Troubleshooting for large scale deployments as in ADSL2

3.3.8 Migration paths

There seem to be two distinct approaches to migrating to VDSL 'big bang' and 'incremental'... In the 'big-band' scenario an overlay network is developed and rollout is staged independent of the existing broadband services, that are mainly delivered over ADSL. In this approach, a large-scale network has to be provisioned even before the arrival of customers. While service penetration is low largely unused cabinets must be deployed, with all the fibre back haul and back-office equipment to support it. The other approach is gradual, making the maximum use of legacy investment to limit financial risk and borrowing.

In the first scenario, new technologies can be exploited fully, and lower equipment cost is promised. The Ethernet solution is feasible for this approach. Exploiting existing infrastructure makes a move away from ATM very problematical.

One of the major advantages of the gradualist approach is that customers can be drawn into increasing bandwidth consumption. For instance, the first step might be to deploy cabinets with line terminations that can do ADSL2, ADSL2+ or VDSL2 by software switch¹. Existing customers with modern ADSL2 modems can take advantage of the higher speed ADSL from the cabinet. Consequently existing customers can be sold new service offerings without the full-scale launch of VDSL. This enables the successive deployment of cabinets to be amortised by virtue of increased ADSL revenue without the need for major core network upgrades. When there is sufficient coverage of capability a whole city can be enabled for VDSL very quickly, but with low risk.

¹ Implementations that can support VDSL2, ADSL2+, ADSL2 and even ADSL have been envisaged since the outset of work on VDSL2. There are two factors that may delay availability of interoperable hardware. The first is that providing +20 dBm needed for ADSL from a line driver with up to 30 MHz of analogue bandwidth. This is not likely to be a limiting factor for cabinet deployment. The second is the prioritisation of interoperability testing that will give second priority to ADSL2/2+. This may delay availability, but implementations will be based on existing well-tested firmware and so interoperability should be easier to establish.

In both models the expectation would be that VDSL will provide some service to almost any cabinet customer. However, it might be that the capacity offered would be in the range of ADSL. However, when VDSL modems are available in the customer's premises the option exists to enable a remote DP (distribution point) offers an upgrade path.

All of the above seems predicated on the use of fibre for backhaul. However, the first stages could be linked to the use of ADSL backhaul to the exchange. This could be point to point or pair bonded for higher peak data rate using shared backhaul. This is the transgenerator concept, that can achieve suitably spectrally shaped ADSL2+ or VDSL to used in the cabinet. It can also be used where VDSL is used in building, but again using ADSL as the low cost backhaul and exchange equipment in the interim.

3.4 Migration path from SDSL to next generation DSL offering symmetrical transmission rates (Enhanced SDSL, VDSL, ADSL2 Annex J/M)

3.4.1 VDSL for Symmetric Services

Bandplan 997 [ref. ETSI 997] is nominally symmetric, however at long reach the plan favours downstream transmission - to the extent that one approach to providing asymmetric services on long lines is to use plan 997 bands DS1 US1 and DS2. So in networks where long reach is a driver, plan 997 is a good way to provide both short reach symmetric services and long reach asymmetric services.

A bandplan based on the current arrangement with different start and stop frequencies could be designed for long reach symmetric operation. However on short loops it would be what might be called anti-symmetric, or heavily biased towards upstream. Such a service would seem of little value.

A better bandplan for long reach symmetric services could be constructed. It would either put the highest downstream band above the highest upstream band (and still transition to a conventional asymmetric bandplan at short reach) or use a much higher number of interleaved bands. However, the use of frequencies below 1 MHz is constrained to be downstream only by the ADSL legacy, so the first option requires the number of bands in the bandplan to be increased from 4 (excluding the optional U0 upstream band) to 5. Unfortunately legacy QAM VDSL cannot support such bandplans, so they may remain theoretical possibilities.

Given the constraints arising from the bandplan, running symmetric services over VDSL must be factored into service planning at an early stage - before bandplan selection is frozen. In networks using plan 997 the scope of VDSL symmetric services is dependent on sub-loop length. In Germany with relatively short and low loss sub-loops the most loops could support symmetric services in the range 10 Mb/s. In the UK with long sub-loops, higher loss cable, and more crosstalk, the scope for such services would be more limited - to full coverage in dense business districts, or for a favoured few close to the cabinet in more typical areas.

In networks using plan 998 or in networks using 997 for long reach asymmetric services, the smaller upstream bandwidth defines the symmetric service that can be supported. This could still be used to provide symmetric services up to circa 5 Mb/s to a large percentage of customers.

An aspect of VDSL2 is that the optional U0 band can be used to provide extra 1 to 2 Mb/s upstream capacity on very long loops. This means that VDSL2 could be used to support SHDSL like rates from the cabinet out to around 2 km. However, this would require VDSL2 to support upstream U0 frequencies up to at least 276 kHz, and have spectrum shaping to meet local spectrum management requirements.

VDSL has the appropriate TPS-TC definitions to support ATM and Ethernet symmetric services. VDSL2 will have these too, but more work is needed to provide the appropriate transport capabilities for TDM services based on plesiochronous and synchronous service models. The definition of native IP transmission over VDSL is for future study.

3.5 Migration path to DSM and DLCM

There seem to be no fundamental conflicts between the MUSE architecture proposals and the development of Dynamical Spectrum Management (DSM) and DLCM.

3.5.1 Migration to DSM

The migration path to DSM is problematic, with the most fundamental issue being that there are serious regulatory barriers to its implementation. A further significant barrier is that DSM will not be rolled out unless there is certainty that the system is stable and will not disturb legacy deployments. Acquiring this confidence depends on having large-scale practical trials which seems fairly unlikely due to the risks. It would therefore seem that the only way to deploy DSM will be by small incremental steps, where each step has controllable risk, and the effects of each step can be fully evaluated before implementing the next step.

Operators in the US have experimented with highly managed DSM but there is as yet no experience of autonomous DSM in a real network. It would seem likely that incumbent operators will be very cautious about deployment of autonomous goal seeking equipment in the network - even without the constraints of Local Loop Unbundling. DSM requires that network exploitation goals be defined to control the behaviour of all autonomous modems. The definition of these goals is itself a major roadblock to deployment.

A critical problem with DSM is how to estimate the capacity target for each modem. Classical DSM requires that all modems seek the same goal. However, the situation will be confused by the existence of high penetration levels of legacy technology that may not be able to co-operate, and the desire of operators to offer a range of services. In order to extract the large claimed benefits, it is necessary to set the objective close to the optimum, but the optimum is hard to define. In an unbundled environment it will be necessary to achieve industry consensus on how to set this target or targets and, at present, network operators do not know how to do this.

The egalitarian objective of politeness in the goal of a common service objective runs counter to much current business planning, which favours providing as much capacity as possible to customers near the exchange. This paradigm is strengthened by the observation that long loop performance is limited as much by inherently uncooperative extrinsic noise sources as by the behaviour of other systems in the plant. Another problem of DSM is that the signal to noise margin available on most lines will be reduced to enhance service rates on longer loops. There is a correlation between operating margin and fault reports. This effect equalisation of operating margin could be a significant increase in maintenance activity and OPEX.

More information on DSM is provided in MUSE deliverable DTF2.2 "Position paper on DSM and DLCM". It is still not clear that there is a migration path to DSM, but the issue is being further studied in MUSE Subproject B.

3.5.2 Migration to DLCM

The pathway to DLCM deployment is somewhat clearer than is the case for DSM. Using proprietary intelligent management systems it is already possible to gain advantages from line-by-line performance monitoring and selective adjustment of line coding parameters.

There seem to be no fundamental regulatory implications.

Potential benefits and risks from DLCM are more readily apparent. Benefits are improvements in service reliability/availability with reduced levels of customer complaints, less truck rolls and hence lower OPEX for network operators. The main risk is that the DLCM adjustment of the FEC/Interleaver configurations for a given line disrupts the service for that line. (For legacy equipment application of revised FEC/Interleaver settings might require a retrain). A secondary risk is that the optimum transport configuration is not compatible with service promises. For example, adding extra latency may be necessary to correct frequency burst erasures, but the resulting service latency may then exceed customer's requirements for an application such as network gaming.

Limited DLCM improvements can be brought about for legacy equipment – the only available options being to invoke interleaving and/or reduce the effective bit-rate.

Improved algorithms to characterise the noise environment

The first stage of DLCM operation is diagnosis of the prevailing noise environment in order to differentiate between crosstalk noise, RFI, isolated or repetitive impulsive interference and simple changes of line characteristic due, for example, to such effects as moisture ingress, temperature change or cable joint problems.

Information required by DLCM to permit evaluation of line quality includes the following DSL link parameters for both the upstream and downstream directions:

- Symbol-by-symbol SNR margin
- Bit allocation tables and line attenuation estimate
- The used FEC codewords and interleaver depth settings
- The far-end FEC reports on corrected and non-correctable codewords
- Values of FEQ coefficients
- The far-end reports on errored seconds counts
- Reported code violations or symbol erasures

With a log (history) of appropriate DSL link information gathered from DSLAMs, including parameters such as those identified above, and knowledge of the service requirements (required bit-rate, maximum acceptable delay) there are many possible algorithmic approaches that can be taken to determine the perceived noise conditions and effect application of the optimal line coding configuration.

The requirements of DLCM have a number of implications on standardisation; the most significant impact is expected to be on DSL modem standards and the associated testing standards. DLCM operation puts an increased significance on the requirement for more extensive and flexible FEC and Interleaver capabilities (the range of operating values and control of configurations), and on the accuracy and consistency of all reported parameters.

Some requirements for DSL standards improvement, derived from consideration of DLCM that have already been identified, are:

- Support of erasure-driven FEC decoding (to increase efficiency of the FEC);
- New MIB parameters allowing operators to configure and observe configuration settings of FEC and interleaver;
- Support of the extended range of INP values (INP is currently specified with a maximum value of 2 DMT symbols; it is proposed to extend up to 32 symbols), with a corresponding increase in the range of interleaving depth;
- Mandatory support of all appropriate valid values of S and D for a given latency path - to ensure that multiple bearer channels operating with different latencies are capable of being equivalently protected;
- Tighter specification is required for how SNR margin is determined.

It is likely that over time DLCM will become a part of all DSL network management, with successive improvements to modems and network management methods being applied. This will naturally be lined with improved per-line diagnostics and sub-loop qualification capabilities in VDSL remotes.

This extension of DLCM makes sense in small remote multiplexers, where it can substantially reduce operational costs. It does this by removing the need for technical staff to visit the remote to do loop qualification, and thereby enabling so called zero touch service turn-up in a scenario where all lines are pre-provisioned, and can be enabled via network management.

4 DSL TRANSPORT LAYER EVOLUTION

4.1 Introduction

Packet based IP content dominates increasingly the traffic in the Access Networks and IP develops to the convergence protocol. Today's services migrate to IP, for example telephony on the basis of Voice over IP (VoIP). So future Access Networks have to be packet optimised in order to handle the increasing IP traffic with its different service requirements. The traditional aggregation technologies based on ATM and SDH are not optimised for IP aggregation and delay the broadband Access evolution due to the high price level.

One alternative could be the Ethernet technology. Ethernet is a connection-less frame-based technology, compared to cell-based connection-oriented ATM and has its roots in Local Area Networks (LANs). It is standardized by the IEEE, which specifies control functions on ISO/OSI Layer 2 and the Layer 1 characteristics of a number of physical interfaces.

Since the development of the Gigabit Ethernet standards in 1998 Ethernet was used also for Carrier Networks. The Ethernet standardisation philosophy is to keep it simple and cheap. That offers also for carriers the chance for introducing cost optimised introduction of Ethernet based broadband technologies in the Access Networks. Especially led by the Asia-Pacific region, DSLAMs and Access Networks based on Ethernet and not on ATM are currently introduced including applications like Voice or Video over IP.

Following some Ethernet migration and integration options are discussed starting from the existing ADSL platform. It identifies main drivers for a migration towards Ethernet from operator's view and discusses possible migration steps in the last mile.

4.1.1 *Main drivers for a migration towards Ethernet*

Ethernet is known as a technology with the potential to offer a range of advantages, e.g.:

- High data rates with lower CAPEX due to its simplicity and volume production,
- Lower OPEX, because the installation, provisioning and maintenance of Ethernet equipment is easier than legacy SDH/ATM/FR equipment,
- Ethernet evolves to the standard customer interface (e.g. DSL NT),
- More efficiency, because Switched Ethernet provides an aggregation layer and Ethernet is optimised for IP transport,
 - Ethernet offers an efficient multiplexing mechanism
- Extended service offering, because Ethernet allows an easy implementation of different service classes and additional functionalities (e.g. Layer 2 VPN services, Multicast Bandwidth on Demand),

4.1.2 *Carrier requirements*

Ethernet used in Carrier Networks has to realise the carrier requirements. On the basis of this fact the market offers a range of "Carrier Class" or "Carrier grade" products. The term "Carrier Class Ethernet" is not clearly defined and vendors use it in order to describe their Ethernet solutions for Carrier Networks. The implantation of additional functions to make Ethernet "Carrier Class" reduces the CAPEX advantage of native Ethernet and so Carrier Class Ethernet solutions are a trade-off between functions and costs.

Essentially Ethernet for Carrier Networks has to solve following topics:

- Quality of Service (QoS)
- Protection mechanisms
- Operation, Administration, Maintenance (OAM) support
- Scalability (the need to address and separate thousands of customers - Customer/Service separation)
- Security

4.1.2.1 Ethernet OAM standardisation

To enable deployment of Ethernet systems in carrier networks Ethernet OAM tools are needed to manage the networks. Currently there are standards bodies such as the ITU Study Group 13, IEEE 802.3 Clause 57 (802.3ah), IEEE 802.1ag Connectivity Fault Management, and the Metro Ethernet Forum (MEF) which are driving towards consistent recommendations and standards for Ethernet OAM..

ITU

In the ITU-T Recommendation Y1730 (Requirements for OAM functions in Ethernet-based networks and Ethernet services) the following OAM functions are defined as mandatory:

- Continuous Connectivity check (CC)
- Alarm suppression function
- Loopback
- Traceroute
- Discovery
- Performance monitoring
- Survivability function (e.g., protection switching, restoration, etc.)

Metro Ethernet Forum (MEF)

MEF defines Ethernet Services for compliant Metro Ethernet Networks (MENS).

The MEF Technical Specification “Service OAM Requirements & Framework” provides requirements and framework for Service OAM within MEF compliant MENS.

IEEE 802.3 Clause 57 (802.3ah)

The IEEE 802.3ah Ethernet in the First Mile (EFM) aims to adapt the Ethernet concept to physical circumstances and transport requirements of the telecommunication access network. The standardisation addresses various subscriber access network topologies (P-t-P, P-t-MP), Physical Layer Specifications (for copper and fibre) and OAM aspects.

- Supported subscriber access network topologies are:
 - Point to multipoint on optical fibre – EFMP or EPON

- Point to point on optical fibre - EFMF
- Point to point on copper – EFMC, (includes an optional specification for combined operation on multiple copper pairs)
- Addressed Link OAM functions are:
 - Remote Failure Indication
 - Remote Loopback
 - Link Monitoring

The EFM OAM specification supports only a subset of the user-plane OAM requirements (defined in Recommendation ITU-T Y.1730). Following OAM aspects are not addressed:

- Station management
- Protection switching
- Provisioning and bandwidth allocation
- Speed/duplex negotiation
- End to end OAM communication

IEEE 802.1ag - Connectivity Fault Management

This standard specifies protocols, procedures, and managed objects to support transport fault management. These allow discovery and verification of the path, through bridges and LANs, taken for frames addressed to and from specified network users, detection, and isolation of a connectivity fault to a specific bridge or LAN.

Connectivity Fault Management comprises of four categories of messages:

- Continuity Check Messages (CC)
- Path Trace Messages
- Loopback Messages
- Alarm Indication Signal (AIS) Messages

4.1.2.2 Basic requirements for OAM

Today, Ethernet does not provide a standardised End to end OAM communication **which allows to supervise the whole path between RGW and ASP**. Link OAM specified by IEEE 802.3 Clause 57 only enables to monitor and troubleshoot an individual Ethernet link.

The existing IP troubleshooting protocols (e.g. SNMP, IP Ping, IP Traceroute), which are often used to manage Ethernet networks, will not work unless the Ethernet layer is operating properly. In addition, this requires an IP overlay for management and troubleshooting of layer 2 Ethernet.

DSL access is commonly used as a virtual leased line connection between CPE and BRAS. When considering OAM functions, Connectivity Check (achieved by Loop Back mechanisms) seems to be the most useful functionality. Most of existing trouble tickets are related to CPE problems, so L2 OAM is primarily required to check the DSL line is working correctly. In order to do this, the following basic requirements are to be met:

- End to end visibility on L2 between BRAS and CPE (with or without a PPP or DHCP session being established)
- Unique point to point connection between CPE and BRAS within layer 2 for addressing customer connection(s)
- Use of a default Loop Back ID when addressing the connection endpoint at the CPE, combined with connection ID which assigns the virtual connection between CPE and BRAS. This provides a unique addressing scheme for DSL connections between CPE and BRAS (e.g. administering the CPE's MAC addresses is too complex for operation in a mass market environment due to the fact that various CPE's could be connected to the open U-interface)

Management protocols are required which provide per-customer or per-service granularity to manage the individual layer 2 Ethernet service connections provided to customers. In addition, such protocols should support p2p, p2mp and mp2mp connectivity.

IEEE 802.1ag specifies Service OAM that provides monitoring and troubleshooting of end-to-end Ethernet service instances. It is recommended to consider this specification for the GSB standard.

4.2 Migration steps

Starting from the existing ATM based ADSL platform towards an Ethernet based DSL platform different migration and integration steps are thinkable. Figure 4.1 gives a schematically overview of the possible intermediate steps, related to the DSL-system components (NT ↔ DSLAM). It corresponds with the migration and integration scenarios described in Deliverable DA2.3 "Network architecture migration mechanisms – consolidation".

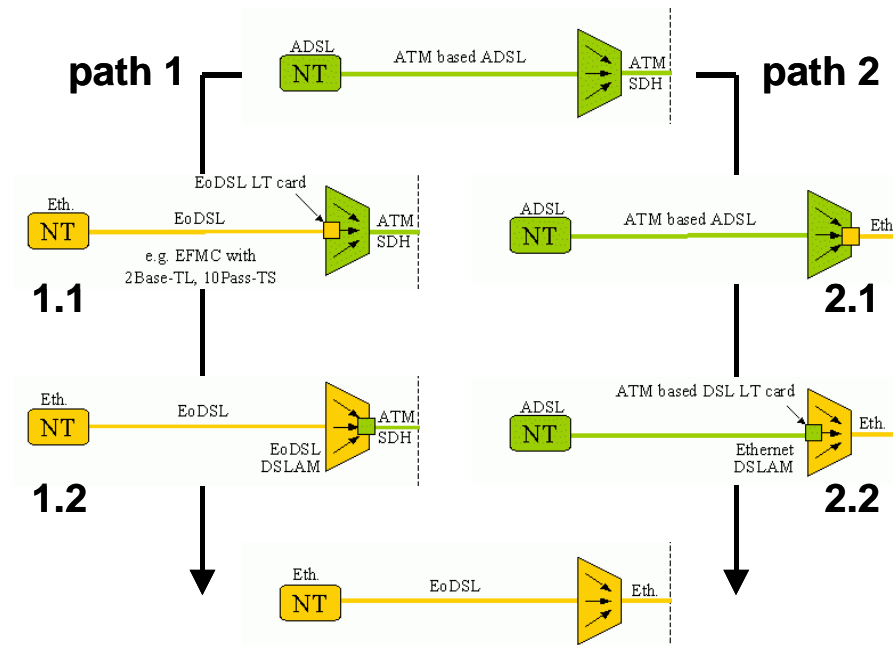


Figure 4.1: Paths of Ethernet migration in the first mile

The starting situation is that most operators have huge numbers of ATM based ADSL lines installed and working. The last mile DSL drop as well as the DSLAM including uplink interface are based on ATM.

A migration causing considerable changes in the network will be made only if one or more of the described motivations (section 2.2) meet the operator requirements (section 4.1.2). In general a direct migration from full ATM (top) to full Ethernet (bottom) is possible. As the exchange of the installed ATM-based equipment is connected with high investments not all existing ATM based ADSL lines will be substituted but rather one or more intermediate steps are more realistic.

In general there are two possible ways to introduce Ethernet in the Access platform:

- Migration model: Ethernet solution substituting existing ATM based DSL platform parts and
- Overlay model: Ethernet solution running in parallel to ATM based DSL connections.

Coexistence issues

Different types of DSL connections are running in parallel as a migration situation regards primarily the possible coexistence of different DSL flavours (ADSL ... VDSL) on one physical transmission medium (same cable route, same cable). Feasibilities or obstacles connected to the various DSL technologies are discussed in chapter 3 - "DSL physical layer evolution". Which transport protocol is running over this transmission primarily does not matter. However, it is possible that a different DSL flavour also implies a different link protocol: ADSL will likely remain ATM based, while emerging VDSL lines will mostly be Ethernet based.

Then, as a second issue it can be answered whether components (line cards) with different transport protocol and, more important, with other OAM implementations/functions can be integrated in one access node and in the management system. The functions must then be mapped on the common used aggregating technology.

Migration paths

Theoretically a migration to Ethernet can be forced starting from the subscriber network (path 1) or from the aggregation network (path 2).

Path 1: It seems to be obvious, that if the DSL technology must be upgraded to get higher bit rates or higher reach, in the same step one can migrate also to Ethernet based transport technology. Although the idea might make sense problems appear among others things especially with the mapping of OAM information in mixed scenarios.

Path 2: The migration of Ethernet from the Network edge to the DSLAM is more consistent when an upgrade of the subscriber DSL bandwidth or a growing subscriber penetration causes a capacity bottleneck on the higher levels of the Aggregation Domain. In addition, the introduction of service enabling functions (QoS, Multicast) is a driver for path2.

But a general problem of hybrid ATM/Ethernet scenarios is the interruption of the established ATM-based OAM flows by the Ethernet network part. This requires an introduction of new OAM processes, including mapping mechanisms between ATM-based and Ethernet-based OAM procedures.

In the following arguments for or against the subsequent described Ethernet migration options and integration concepts are discussed.

- Option 1.1: ATM DSLAM & Ethernet based DSL link
- Option 1.2: Ethernet DSLAM and DSL link
- Option.1: ATM DSLAM uplink is Ethernet
- Option 2.2: Ethernet DSLAM & ATM based DSL link

Option 1.1:

Migration option 1.1 is characterised by an ATM network with ATM based DSLAM. Ethernet based DSL line terminal cards (LT-cards) can be plugged into the ATM based DSLAM. So only the DSL link between LT and NT is based on Ethernet and terminated at the DSLAM.

A possible driver for this kind of migration is the introduction of additional functions at new CPEs (NT) which can not be offered so far over the ATM based CPEs (e.g. QoS). But this idea requires at least an enhanced ATM based DSLAM with Ethernet based line-cards, which are also able to map the functions to ATM upstream network. Most of the existing ADSL DSLAMs do not support Ethernet as drop technology.

Another motive for option 1.1 could be the necessary upgrade to a new DSL line rate (linecard respectively). One can assume that this substitution could also be used to make the step to Ethernet at the same time. But this as well can not be made with the "old" DSLAM because the increasing line rates at the existing DSLAM may lead to bottleneck in the MUX matrix or at least in the upstream link as well. Therefore the flanging of Ethernet DSL to the existing ATM platform is not recommended.

Option 1.2:

Migration option 1.2 is characterised by Ethernet based DSLAM with Ethernet based DSL lines to the NTs. The DSLAM uplink is based on ATM and connects to the aggregation switches.

This means that the Ethernet based functionality is introduced only between customers's CPE and the Access Node and hence must be translated into the ATM network. As a migration approach, this only can be taken into consideration if not all existing DSL lines have to be changed to Ethernet. This would be too expensive and laborious. An option could be to install new and enhanced Ethernet links, not over the ATM DSLAMs, but to operate Ethernet and ATM DSLAMs in parallel on the same ATM based aggregation platform for a limited time period of migration. But it is more reasonable to put the transition point more centralised.

It is also possible to have Ethernet over ATM in the first mile terminated in an Ethernet DSLAM which provides an ATM uplink to a legacy network and an Ethernet uplink to the upgraded aggregation network. As such, the platform already features a higher throughput matrix in Ethernet and is future ready for Ethernet first mile and/or Ethernet aggregation networks.

Option 2.1:

Migration option 2.1 assumes an Ethernet migration starting from the aggregation network. The existing DSL platform with ATM DSLAMs and modems/NTs are left as they are, but the DSLAM uplink is realised with an Ethernet interface.

This can be motivated by an upstream bottleneck. But the argument of when one must upgrade the limited DSLAM uplink, it also offers the opportunity to shift not only to higher bit rate but also, at the same time, the possibility to change to e.g. GbE. Notwithstanding, on the one hand not all especially old DSLAMs provide the possibility, and on the other hand, it will not resolve the problem of limited capacity of the DSLAM multiplexer matrix.

Option 2.2:

Migration step 2.2 considers a new Ethernet based DSLAM as part of a new aggregation platform. Existing ATM based DSL lines can be terminated in this DSLAM. (LTs and NTs are still ATM based).

A possible driver is the exchange of DSLAMs while keeping a large base of ADSL links working, mainly the modems at the customer premises. Doing this for all working DSL lines would be too laborious for switching over the running lines. This can only make sense in a very late phase of migration to Ethernet, when most of the customers are already being switched over to the new Ethernet platform. Only the few ADSL lines left could be switched over from the old DSLAM to the new, intending to release the old ATM platform. But even then, it would be more reasonable to change the DSL link technology for some users to get a consistent network.

Summary

The described intermediate migration options have serious drawbacks complexity and additional efforts combined with intervention in running systems. The case of that the whole access domain is based on Ethernet can, on the other hand, only be seen as the end stadium of the Ethernet migration. A temporary coexistence of both transport layers in separated parallel DSLAM platforms in the access domain is a more realistic approach.

From today's perspective, a migration to Ethernet based DSL with hybrid ATM/Ethernet networks (e.g. ATM based aggregation and Ethernet based DSL) causes the problem of the interruption of the established ATM-based OAM flows by the Ethernet network part. New OAM processes, including mapping mechanisms between ATM-based and Ethernet-based OAM procedures must be specified. ..

5 SUMMARY

Chapter 2 identifies motivations and guidelines for migration from current DSL deployments to next generation DSL starting from current network situations and involving technical analysis results of MUSE. Migration steps are described starting from an ADSL base to VDSL2.

The Introduction of enhanced or new DSL flavours is driven by:

- Low cost bandwidth upgrade
- Low cost reach upgrade
- Low cost service enabling
- Reduction of operation expenses

VDSL2 includes all the benefits of ADSL/2+ but it comes with higher speeds than VDSL1. It offers the chance of a gradual, flexible, and cost efficient upgrade of the existing xDSL platform, additionally it supports Ethernet or ATM on Layer-2. So it seems to be the ideal DSL technology. But currently there is only a low availability of VDSL2 techniques because the standard was approved and announced by the ITU-T on May 27th, 2005. As VDSL1 has no ADSL compatibility, it makes sense to migrate via an ADSL2+ solution that allows a VDSL2 upgrade.

Also the FTTE approach makes sense for high rate ADSL2+ or VDSL2 solutions and can be seen as a migration step. Usually there is a part of a Service Area around the Local Exchange that can be reached by a specific high rate DSL technique without any infrastructure workings. Especially in urban areas a considerable number of customers can be connected on the basis of ADSL2+ or VDSL2.

The offering of a new Service generation that is optimised for packet oriented traffic with very high data-rates and Quality of Service (QoS) provision probably requires the introduction of a new DSLAM generation. Considering the state-of-the-art it does not make sense to upgrade the platform on the basis of ATM DSLAM techniques with ATM uplinks.

Figure 4.2 depicts some migration options and features of a new DSLAM generation which give the operator the needed flexibility. An advanced Ethernet/IP DSLAM should be able to substitute the installed ADSL base by providing line cards which support ADSL lines. While the availability of low cost VDSL2 techniques is insufficient the DSLAM should support ADSL2+ line cards. Later the DSLAM can be populated with cheaper VDSL2 line cards which enable ADSL/2/2+ or VDSL2. In addition, it is necessary support an adequate optical feeding system to connect remote DSLAMs on the basis of FTTCab or FTTB.

The FTTCab concept enables to reach the majority of customers with very high data rates provided by ADSL2+ or VDSL2.

There are however also large initial investments for the FTTCab concept due to the high effort for the new optical infrastructure and the usually required upgrade of the existing Cabinet locations regarding outside capability, power supply and air-conditioned environment cause also for the FTTCab concept high initial investments. On the other hand, in urban areas the Main Cable section usually has a large installed duct base that enables a cost optimised fibre roll-out up to the Cabinet. In addition, there are some concepts to keep down the investments for the Cabinet location, Mini DSLAM with remote powering, Central cabinet migration concept with local powering and VDSL over optics.

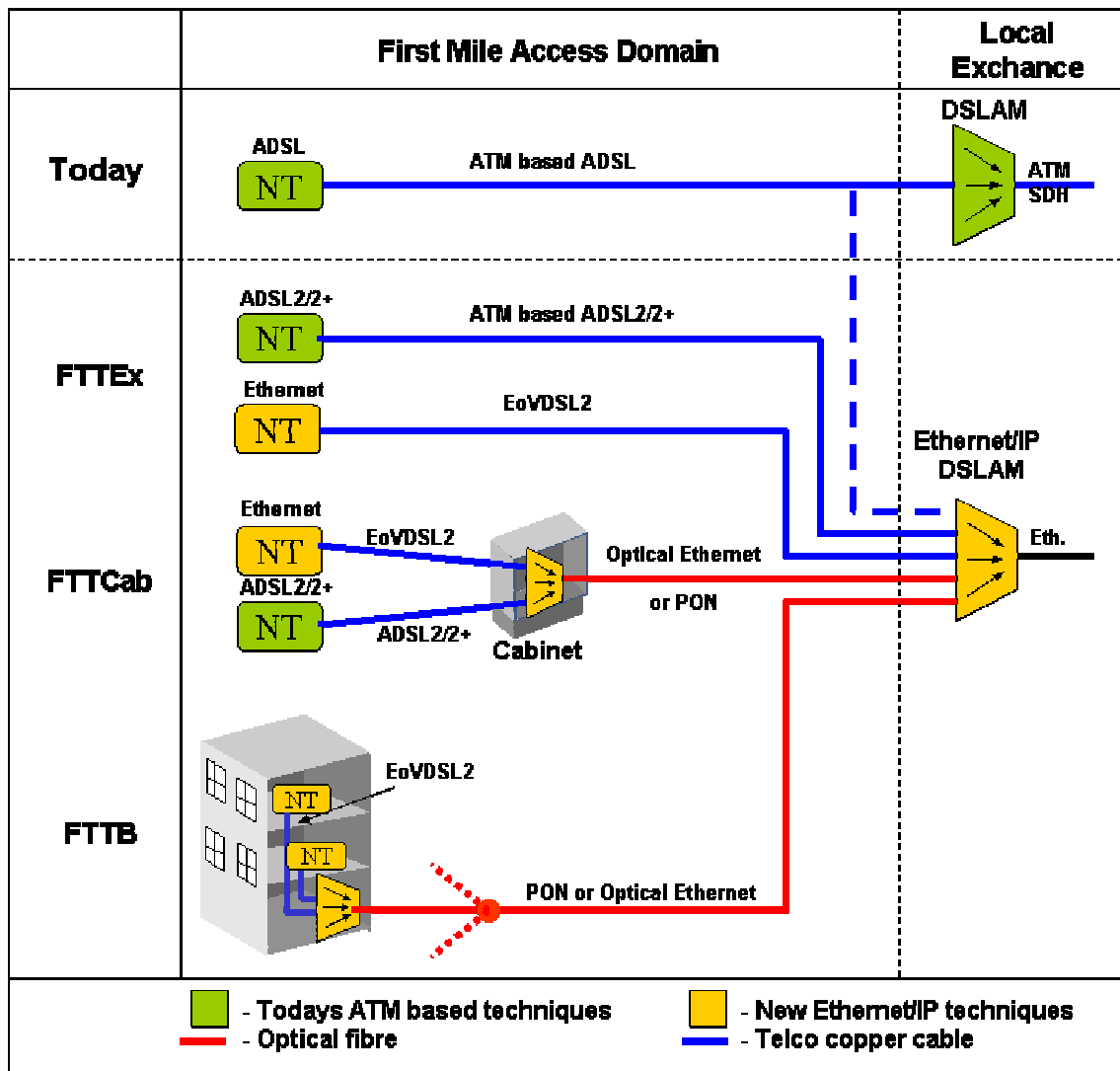


Figure 4.2 First Mile Migration Option

Chapter 2 describes following alternative remote powering concepts including some quantification of what is possible in terms of reach and output wattage:

- 310 V Remote Powering using existing copper pairs
- 110 V Remote Powering using existing copper pairs
- Remote powering over power cables using Medium voltage AC powering (1000V)
- Remote powering over power cables using 110V DC
- Cluster Powering
- Powering from customer network side

In case of a FTTB concept, a DSLAM with optical uplink can be installed inside of buildings, e.g. in the basement. In general a FTTB concept is more expensive than a FTTCab approach but it can be an economical solution especially for multi dwelling buildings or office buildings and Greenfield situations. There is no penetration limits estimated (limits at very high bit-rates caused by in-house cabling). The data rate are limited by the in-house cabling and the applied technology.

Two migration paths were identified. Migration path 1 (CAPEX minimised, low risk migration) aims on a Mass market roll out and minimises the economical risk if the customer penetration increases slowly. Path 1 starts with a FTTEEx approach. Around the Local Exchange all customers which can be reached by a specific high rate DSL technique will be connected without any infrastructure workings. Especially in urban areas a considerable number of customers can be connected on the basis of ADSL2+ or VDSL2. In the next step a FTTCab roll-out is usually the most efficient solution for the Mass market. Concepts to keep down the investments for the Cabinet location must be considered, e.g. Mini DSLAM with remote powering, Central cabinet migration concept with local powering and VDSL over optics. In the last step, a gradual connection of buildings towards FTTB is possible depending on bandwidth demand per customer. A DSLAM with optical uplink can be installed inside of buildings, e.g. in the basement.

Migration path 2 is an option for service offerings with data rates higher than 25 Mbit/s that requires more and more an FTTB approach. On the other hand, it is the solution for deployments in selected areas with powerful duct (fibre) infrastructure (dense urban, urban areas), where FTTB becomes cost competitive to FTTCab and where it is not possible to install new street cabinets and alternatives are too expensive or in areas with high competition (Strategic positioning).

Chapter 3 discusses migration aspects of different xDSL technologies. Migration motivations have been identified for ADSL2, ADSL2+, VDSL1 and. VDSL2.

A migration to ADSL2 is motivated by some new features. The main driver will be the reduction of operational costs, but ADSL2 also offers new or advanced services.

Major migration aspects are the co-existence to ADSL, backwards compatibility and addressing of necessary changes in the network, e.g. the element management. Interoperability will remain an important issue for ADSL2 which leads to new tests and test facilities.

The main driver for ADSL2+ will be the duplicate of frequency ranges which will increase the data rates and the reduction of interferences in the loop. Moreover, all those drivers obtained before in the ADSL2 are also main drivers here, because it must be remembered that ADSL2+ is based on ADSL2, getting the best from it and improving it to supply new features as fast start, spectral channelling and an efficient energy management including modes of low consume, stand-by, etc.

VDSL deployment in the cabinet would prevent simultaneous VDSL deployment in the exchange over the same cable plant using the same power spectrum and band plan. This is because downstream signals injected at the cabinet will be much stronger in the final section of cable than signals in adjacent pairs injected at the exchange. This has the consequence that the FEXT caused by cabinet systems will tend to drown the weak signals arriving from the exchange. This effect is known as the near-far problem.

Chapter 3 discusses the migration path to DSM and DLCM. There seem to be no fundamental conflicts between the MUSE architecture proposals and the development of Dynamical Spectrum Management (DSM) and DLCM.

The migration path to DSM is problematic, with the most fundamental issue being that there are serious regulatory barriers to its implementation. A further significant barrier is that DSM will not be rolled out unless there is certainty that the system is stable and will not disturb legacy deployments.

DSM requires that network exploitation goals be defined to control the behaviour of all autonomous modems. The definition of these goals is itself a major roadblock to deployment.

A critical problem with DSM is how to estimate the capacity target for each modem. Classical DSM requires that all modems seek the same goal. However, the situation will be confused by the existence of high penetration levels of legacy technology that may not be able to cooperate, and the desire of operators to offer a range of services. In order to extract the large claimed benefits, it is necessary to set the objective close to the optimum, but the optimum is hard to define. In an unbundled environment it will be necessary to achieve industry consensus on how to set this target or targets and, at present, network operators do not know how to do this.

The egalitarian objective of politeness in the goal of a common service objective runs counter to much current business planning, which favours providing as much capacity as possible to customers near the exchange. This paradigm is strengthened by the observation that long loop performance is limited as much by inherently uncooperative extrinsic noise sources as by the behaviour of other systems in the plant.

Another problem of DSM is that the signal to noise margin available on most lines will be reduced to enhance service rates on longer loops. There is a correlation between operating margin and fault reports. This effect equalisation of operating margin could be a significant increase in maintenance activity and OPEX.

More information on DSM is provided in MUSE deliverable DTF2.2 "Position paper on DSM and DLCM". It is still not clear that there is a migration path to DSM, but the issue is being further studied in MUSE Subproject B.

The pathway to DLCM deployment is somewhat clearer than is the case for DSM. Using proprietary intelligent management systems it is already possible to gain advantages from line-by-line performance monitoring and selective adjustment of line coding parameters. There seem to be no fundamental regulatory implications.

Potential benefits and risks from DLCM are more readily apparent. Benefits are improvements in service reliability/availability with reduced levels of customer complaints, less truck rolls and hence lower OPEX for network operators. The main risk is that the DLCM adjustment of the FEC/Interleaver configurations for a given line disrupts the service for that line. (For legacy equipment application of revised FEC/Interleaver settings might require a retrain). A secondary risk is that the optimum transport configuration is not compatible with service promises. For example, adding extra latency may be necessary to correct frequency burst erasures, but the resulting service latency may then exceed customer's requirements for an application such as network gaming.

Limited DLCM improvements can be brought about for legacy equipment – the only available options being to invoke interleaving and/or reduce the effective bit-rate.

Chapter 4 identifies Carrier requirements for Ethernet based DSL with the focus on Operations, Administration and Maintenance (OAM). Today, Ethernet does not provide a standardised End to end OAM communication **which allows to supervise the whole path between RGW and ASP**. Link OAM specified by IEEE 802.3 Clause 57 only enables to monitor and troubleshoot an individual Ethernet link.

The existing IP troubleshooting protocols (e.g. SNMP, IP Ping, IP Traceroute), which are often used to manage Ethernet networks, will not work unless the Ethernet layer is operating properly. In addition, this requires an IP overlay for management and troubleshooting of layer 2 Ethernet.

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