Exploration Programmes:
Corporate Technology Explores Future Telecommunications

VDSL Based Broadband Access Network

VDSL (Very high speed Digital Subscriber Line) is a new access technology able to deliver more than 10 Mbit/s downstream: the first standard compliant products are expected end of this year. VDSL provides an interesting alternative to the fibre-to-the-home solution for distributing TV services. The inherent complexity of spectrum management is compensated by the possibility to deploy broadband services without too important infrastructural changes, as shown by the commercial VDSL deployment of Qwest.

The Exploration Programme "Broadband Communication Opportunities" explores new broadband service and communication opportunities enabled by the new 10 Gigabit Ethernet technology, managed all-optical networks, the evolution from ADSL to broadband heterogeneous access networks (fixed and mobile/wireless) and peer-to-peer network models.
With its Exploration Programmes, Corporate Technology is exploring telecommunication technologies and new service possibilities with a long-term view of 2-5 years. Further, the expertise built up in the course of this activity enables active support of business innovation projects.

FREDERIC PYTHOUD AND
JOHANNES SCHNEIDER

« 1948: IBM's Selective Sequence Electronic Calculator computed scientific data with a speed of 50 multiplications per second using 20 000 relays and 12 500 vacuum tubes. Before its decommissioning in 1952, the calculator produced the moon-position tables used for plotting the course of the 1969 Apollo flight to the moon" [1].

Since then, the performance of computers did not stop increasing, doubling every 21/2-3 years, due to technology and application evolution. The same observation can be made for data communications over telephone networks, as shown in figure 1 for the bandwidthdemand increase of private customers. The extrapolation will lead to a massmarket demand of 1 Mbit/s in 2006, and about 10 Mbit/s in 2015.

You may ask yourself: for which applications? This pertinent question does not seem to be critical. Yesterday for file transfer, today for Internet surfing applications; in the future the bandwidth will certainly be used for TV streaming applications, but who knows?

Taking into account the observed increase of bandwidth demand, independent of technology and applications, it is important for an operator to consider the upgrade of its network, particularly the access network. The fixed network is indeed too precious to deliver narrowband services only and the future is in delivering broadband services: The 1 Mbit/s step for Internet access will be achieved with ADSL transmission tech-

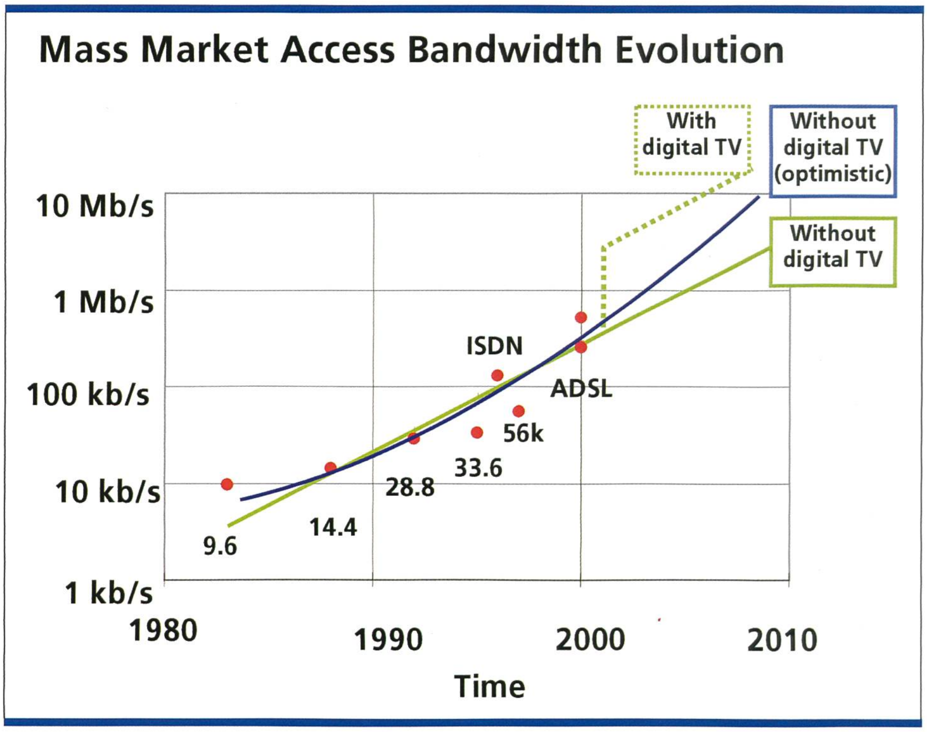

Fig. 1. Overview of the residential customer bandwidth evolution with time. We expect three different scenarios depending on whether or not TV services are to be distributed.

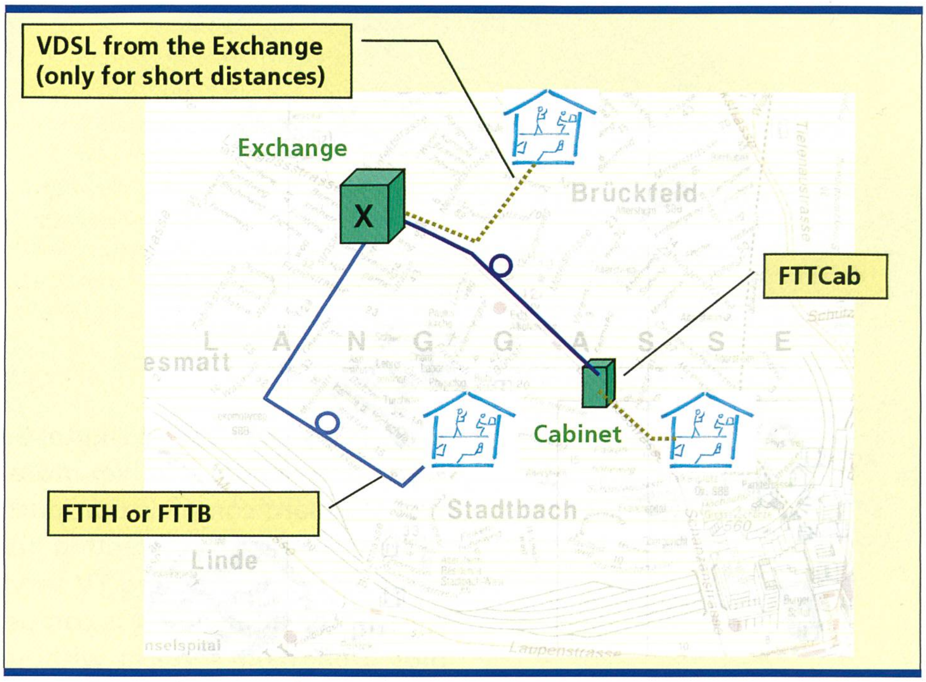

Fig. 2. Three architectures for a requirement of 10 Mbit/s per customer.

VDSL technology can achieve more than 10 Mbit/s downstream on actual copper pair lines (0.3–1.5 km). This capacity corresponds to 2–3 simultaneous TV channels (MPEG2, near PAL quality) and additional broadband Internet access. Note that if we assume a switched digital TV infrastructure, the 10 Mbit/s bandwith can of course be used to offer 150 channels of even more, 3 of them (more than 10 in the future with MPEG4 encoding) to be seen simultaneously by every household.

nology and the motivation then must be to identify key issues to make the network capable of TV delivery: This step (10 Mbit/s) was the scope of a project in the Corporate Technology Exploration Programme "Broadband Communication Opportunities". The project has been realised in tight collaboration with Swisscom's Network Business Unit which is actually responsible for the deployment of ADSL.

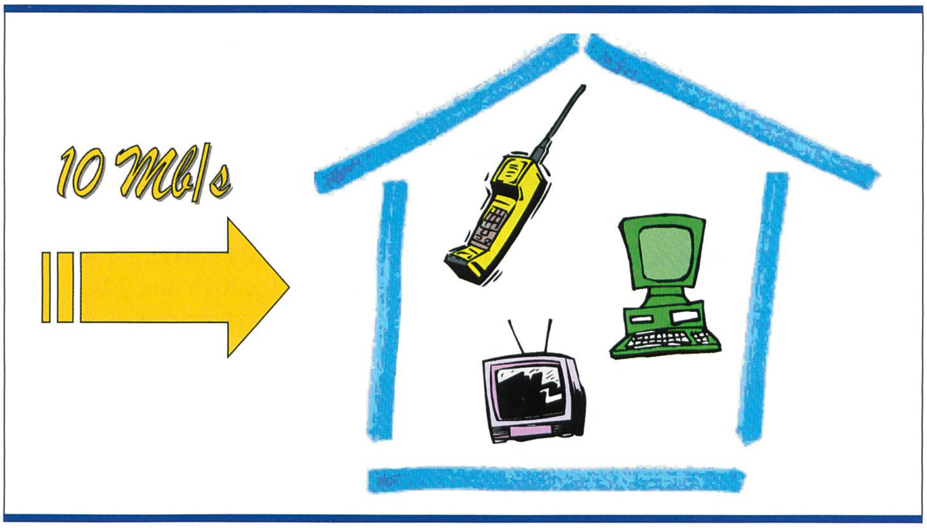

Fig. 3. Typical VDSL scenario: 10 Mbit/s for 2-3 digital TV channels, broadband Internet, and telephony.

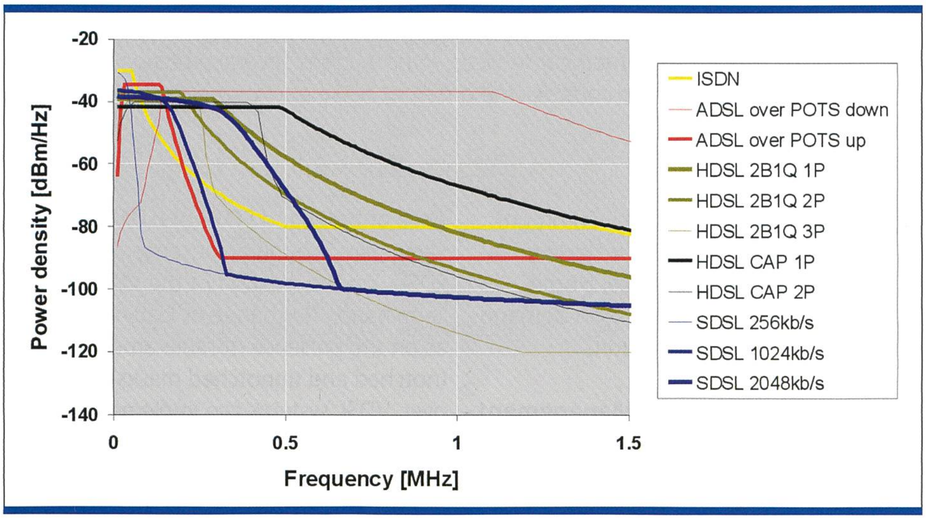

Fig. 4. Overview of power emission masks of xDSL systems. The high number of systems to be considered tends to increase the complexity of spectrum management.

VDSL: The Last Child of the xDSL Family

VDSL is the last child of the xDSL family as presented in table 1. The great advantage of xDSL technologies [2-5] is that they are made for copper pair cables and thus allow to re-use the access network infrastructure originally deployed for telephony services.
VDSL is specially optimised for high bit rate and therefore short distances on copper wire. It is defined in several versions as mentioned in the ETSI standard (table 2), with symmetrical bit rate for business use and asymmetrical bit rate for residential customers.

VDSL Architecture

The average length of the copper line of telephone customers in Switzerland is about 2.5 km, too high to connect all customers by using VDSL from the Exchange. Due to its limited reach, VDSL has therefore to be used in adapted architectures as illustrated in figure 2:

- VDSL from the exchange where possible;
- fibre from the exchange to the cabinet and VDSL from the cabinet, also called Fibre To The Cab (FTTCab);
- fibre from the exchange to the building and VDSL within the building, also called Fibre To The Building (FTTB).

Fibres will therefore have to be deployed in a part of the network in all cases. We are addressing the question whether to install fibre to the cabinet (FTTCab) with VDSL last drop, or directly go with the fibre to the home (FTTH). The first choice has the important advantage to reduce the digging cost, by far the most important costs, but brings the necessity of putting active electronic equipment in the network, in small cabinets, and to protect this equipment from humidity and extreme temperatures. The second choice would imply a full upgrade of copper cables with fibre, as well as putting optical equipment at each customer site. This choice is of course very expensive, but certainly long-term proof. Concerning the fibre part of the network, two important variants are planned today: Point-to-Multipoint systems based on passive optical splitters placed in the network (PON, Passive Optical Network systems based on ATM or Ethernet), or Point-to-Point systems like Gigabit Ethernet.

Services with VDSL

Digital TV services are today the major bandwidth consumers. Television distribution using MPEG2 compression techniques requires about 2 Mbit/s for near PAL quality and 4 Mbit/s for near DVD quality. The bandwidth depends of course on the content type: sports films require much more bandwidth that static pictures like TV news presented by a speaker. While the more recent MPEG4 technique allows much higher compression for similar qualities (0,5 Mbit/s for near DVD quality according to Microsoft), it requires much greater computational resources for encoding and therefore generates latency in the case of live TV.
In order to carry 2-3 TV channels as well as broadband Internet and telephony on one transport channel, a minimum throughput of 10 Mbit/s is thus required today (fig. 3). Additional applications like Internet gaming or e-learning could contribute to leverage the high cost of such an infrastructure upgrade.
It is interesting to note that the Network Operator Qwest has already started to deploy commercial VDSL services including TV broadcast, video on demand and fast Internet access. Qwest has already 50 000 customers paying for these ser-

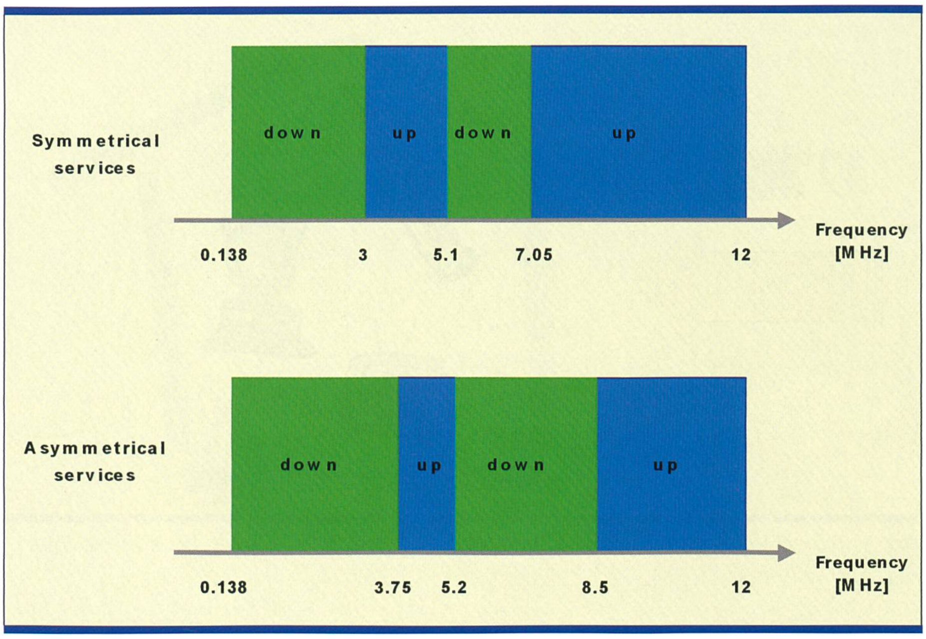

Fig. 5. VDSL band allocation has been planned in two versions: one for symmetrical and the other one for asymmetrical services. In both cases several emission masks are defined (not shown here) to consider the different noise environments in which VDSL will be running.

vices and uses the Next Level Communication broadband platform including VDSL modems and residential Home Gateways. Services like video on demand and gaming are in preparation.

Crosstalk and Spectrum Management

One of the most important problems of xDSL technologies is their sensitivity to crosstalk. Crosstalk is the physical process observed when a modem is running on a copper pair cable. Due to electromagnetic interactions, adjacent pairs within the same cable will receive a part of the signal generated by the running modem. This leads to the observation that xDSL modems running on adjacent pairs disturb each other. The effect increases with the frequency: almost negligible for ISDN (up to about 120 kHz), it becomes important for ADSL (up to 1 MHz), and a very important limiting factor for VDSL (up to 12 MHz). The reciprocal disturbance of xDSL also depends critically on the xDSL mixture present in the cable. Figure 4 shows spectra of ISDN, of different versions of HDSL, as well as ADSL and SDSL.
VDSL is not only sensitive to the presence of other modems, but also disturbs wireless transmission working in the range of 138 kHz to12 MHz (e.g. radio amateurs). For this reason, several power emission masks have been defined for VDSL; they depend on the noise environment (presence of baseband POTS or ISDN in the same pair or bundle, presence of other xDSL), on the location of the VDSL Line Termination (Exchange or Cabinet), as well as on the presence of radio amateurs (notched and unnotched masks). Moreover, VDSL systems can implement 2 frequency plans as illustrated in figure 5: one optimised for symmetrical services and the other one for asymmetrical services.
Despite the important studies on the xDSL crosstalk [7], few established results are available today. Each operator is developing its own spectrum management in order to optimise the network capacity for its needs. A high penetration of xDSL systems, as well as the complexity of crosstalk management indeed first requires a spectrum management and secondly good planning rules. The spectrum management is a recommendation on the xDSL systems to be deployed or not in a network. The planning rules are range estimations to deploy the xDSL systems, take into account the future penetration of xDSL systems, and guarantee a long-term service quality even for future xDSL penetration. A typical example of a planning tool is already available on the Swisscom web site for ADSL services [6].

Conclusions

Today, VDSL technology running on the telephony copper pair cables is a well standardised technology suited for digital TV broadcast, broadband Internet access, and telephony. For a classical telephony operator, VDSL combined with fibre is one of the most serious candidate transport technologies in the access to compete with cable operators by offering TV

xDSL	Bit Rate	Distance on copper pair
HDSL	2 Mbit/s symmetrical	2–4 km
ADSl	0–8 Mbit/s downstream 0–900 kbit/s upstream	1–5 km
SDSL	0.2–2.32 Mbit/s symmetrical	2–4 km
VDSL	symmetrical: 6.4–28.8 Mbit/s asymmetrical: 2–4 Mbit/s upstream 6.4–23 Mbits/s downstream	0.3–1.5 km

Table 1. Overview of the xDSL family with bit rate and distance reach. It is important to note that the distance on copper pair depends very much on the cable quality, as well as on the noise environment (other xDSL running in the same bundle).

Class (Code) of operation	downstream (kbit/s)	upstream (kbit/s)
Class I (A4)	362 × 64 = 23 168	64 × 64 = 4 096
Class I (A3)	226 × 64 = 14 464	48 × 64 = 3 072
Class I (A3)	134 × 64 = 8 576	32 × 64 = 2 048
Class I (A3)	100 × 64 = 6 400	32 × 64 = 2 048
Class II (S5)	442 × 64 = 28 288	442 × 64 = 28 288
Class II (S4)	362 × 64 = 23 168	226 × 64 = 23 168
Class II (S3)	226 × 64 = 14 464	226 × 64 = 14 464
Class II (S2)	134 × 64 = 8 576	134 × 64 = 8 576
Class II (S1)	100 × 64 = 6 400	100 × 64 = 6 400

Table 2. Payload bit rates for VDSL according to the ETSI standard.

services. The critical problem for the moment is the spectrum management where, in addition to the ETSI approach, each operator develops its own tools and experience. Moreover, the absence of commercial standard-compliant products at the moment (the first products are expected by the end of this year) seems to give time to VDSL to populate our networks. As compared to fibre, this technology has the big advantage of using the existing infrastructure. The definitive answer will certainly depend on the evolution of the broadband demand.

Outlook

Commercial VDSL standard-compliant products are promised for the end of this year. Moreover, the FS-VDSL group is planning a demonstrator integrating VDSL for TV distribution. The target price of these products should also stabilise in the next year: assuming them to be very competitive, this would mean a very long life for our old copper pair cables originally installed for POTS. 7

References

[1] Timeline of computer History, http://www.computerhistory.org/timeline/topics/computers.page

[2] "High bit-rate Digital Subscriber Line (HDSL) transmission systems on metallic local lines; HDSL core specification and applications for combined ISDN-BA and 2048 kbit/s transmission", ETSI TS 101 135, September 2000.

[3] "Symmetrical single pair high bitrate Digital Subscriber Line (SDSL)", ETSI TS 101 524, June 2001.

[4] "Asymmetric Digital Subscriber Line (ADSL); Requirements and performance" ETR 328, November 1996.

[5] "Very High speed Digital Subscriber Line (VDSL", ETSI TS 101 270-1, October 1999 and ETSI TS 101 270-2, September 2000.

[6] http://www.swisscom.com/gd/services/wholesale/wholesale-en.html -> ADSL Check (BBCS).

[7] "Spectral management on metallic access networks; Part 1: Definitions and signal library", ETSI TR 101 830, September 2000.

Frédéric Pythoud *is currently involved in Access and Home Networking projects at Swisscom Corporate Technology. He participated actively in the standardisation of ADSL within ETSI-STC-TM6 and GX-FSAN (actually FS-VDSL). He also took part in the EURESCOM projects P614, P915, and P1005. Frédéric Pythoud studied physics at the Swiss Federal Institute of Technology in Zürich (ETHZ) and graduated at Swiss Federal Institute of Technology in Lausanne (EPFL).*

Johannes Schneider *studied physics at the University of Bern and graduated in optics in 1988. He joined the Telecom PTT R&D department in 1989, where he worked on integrated optics until end 1993 and on transmission in the access network, specifically Fibre in the Loop, ATM and interconnection until 1998. In 1999, the work focused on new residential service technology, mainly multimedia and the human-machine interface and in 2000 on Service Management for IP networks, UMTS, and for traditional telephony.*

Abbreviations

ADSL	Asymmetric Digital Subscriber Line
ETSI	European Telecommunications Standards Institute
FTTB	Fibre To The Building
FTTCab	Fibre To The Cabinet
FTTH	Fibre To The Home
HDSL	High bit rate Digital Subscriber Line
LT	Line Termination
PON	Passive Optical Network
POTS	Plain Old Telephony System
SDSL	Symmetrical single pair high bitrate Digital Subscriber Line
VDSL	Very high speed Digital Subscriber Line

Zusammenfassung

VDSL ist das letzte Kind der xDSL-Familie und gleichzeitig das leistungsfähigste. Die Technologie liefert Bitraten bis 23 Mbit/s downstream und 4 Mbit/s upstream auf einem Telefonkupferpaar. Der Preis, der für diese riesige Datenrate bezahlt werden muss, ist die Reichweite des Systems: 0,3 bis 1,5 km, je nach Bitrate. Das bedeutet, dass VDSL in Kombination mit Glasfasern verwendet werden muss, um den Hauptteil der Kunden erreichen zu können. Im Vergleich zu einer reinen Glasfaserlösung (Fiber-to-the-Home) hat VDSL den Vorteil, dass es schneller und zu tieferen Investitionskosten in Betrieb genommen werden kann, da fast keine Installationen von Glasfasern nötig sind. Dagegen braucht VDSL ein genaues Spektrum-Management sowie Planungsregeln, deren Definition komplex ist. Die VDSL-Standardisierung begann vor vier Jahren und führte zum ersten Standard Ende 1999. Trotz dem weltweit ersten kommerziellen VDSL-Einsatz durch *Qwest* scheint das heutige Fehlen von ETSI-konformen VDSL-Produkten kurzfristig den Einsatz von ADSL- und SDSL-Lösungen mit begrenzter Bandbreite (einige Mbit/s) zu begünstigen.