DSL role in the Next Generation Access Networks

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Abstract - *Broadband wired access should be accelerated to at least 30Mbit/s in the next seven years. A migration to an all-fiber network infrastructure requires a massive investment and will take time to complete. Hybrid fiber-copper network topology is cheaper and faster to deploy. The latest DSL technologies will play a key role in transition to the final all-fiber access network.*

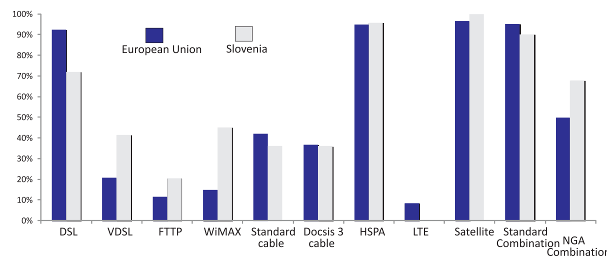

Figure 1. Broadband coverage by technology in EU and in Slovenia [2].

1 Introduction

The Digital Agenda for Europe [1] has two key objectives:

- To provide a basic broadband access * for all citizens by 2013,
- to provide broadband speeds of at least 30Mbit/s by 2020.

Broadband coverage survey study for the EU countries research report by Point Topic [2] shows, that standard broadband is available for more than 96% EU homes. More than 50% homes already have NGA broadband available. A major modernization tasks lies in EU rural areas where 35 million of total 40 million homes are still waiting for NGA. By definition of rurality (less than 100 inhabitants per square kilometre) almost 20% of the EU population is estimated to live in the rural area. General problem is that operators compete to serve more densely areas, leaving others underserved.

DSL is the most important standard fixed line broadband technology in EU today. It reflects the pattern of past investment in the telephone network: where a universal service obligation to provide telephone service has been implemented using fixed-line twisted copper-pair infrastructure then the availability of DSL has naturally followed. Total DSL coverage in EU is 93% and 73% in rural areas. For fixed next-generation access VDSL is the second biggest service with 21% coverage and less than 4% in rural area. Docsis3 cable network is the most important NGA service with 37% coverage. Fiber to the home or business premises (FTTP) coverage in EU is only 12%, but greatest in eastern parts of Europe (40%-60%) because of the limitations of other networks and because of the favourable residential block-building topology.

Broadband standard coverage in Slovenia is a little below the EU average [2]. Slovenia shows relative higher score for the NGA in comparison with the EU. VDSL coverage in Slovenia at 42% is twice the EU average, Docsis3 coverage is 36% and FTTP coverage is at 21%. As in other countries there are huge variations in superfast availability: Ljubljana has 96% NGA coverage and least favoured region has only 30% NGA coverage.

2 Capacity demands and FTTH deployment

Capacity demands are so far growing exponentially fast. Nielsen law states that access bandwidth demands grows 50% per year. This would mean that VDSL2 technology would no longer serve the needs of high end customers in 2016. VDSL2 vectoring can prolong this period for another three to four years. It is obvious that in the next decades only all-fiber access network can serve the future top capacity demands.

FTTH is expensive and time consuming to deploy. In most of the European countries the proportion of FTTH is still less than 5% of all broadband. The deployment of FTTH is a project with a timescale more than ten years. Japan is an illustrative real word example: their companies began deploying FTTH ten years ago under low deployment costs and very supportive regulation, and have converted 45% of access wired lines.

*A basic broadband access is offering only 144kbit/s, while NGA (Next Generation Access) technologies should offer from 50 to 100 Mbit/s.

Hybrid fiber-copper topologies are cheaper and faster to deploy. The costs of exclusively fiber based FTTH technology are several times higher than costs of the present DSL technologies. DSL vectoring should serve in many cases as a cost-effective temporary bridge to the future all-fiber access network (FTTH, FTTP). We expect that new DSL technologies VDSL vectoring and superfast DSL (G.fast) will play a key role in the transition to the final all-fiber wire line access network.

Beside common EU Digital Agenda 2020, most EU countries have their own broadband access capacity and coverage plans:

- Germany: downstream rate 50Mbit/s, with 75% coverage until 2014,
- Finland: symmetric rate 100Mbit/s, 100% coverage until 2015,
- United Kingdom: downstream rate 25Mbit/s, 90% coverage until 2015,
- Austria and Denmark: downstream rate 100Mbit/s, 100% coverage until 2020,
- Sweden: downstream rate 100Mbit/s, 90% coverage until 2020,
- France: downstream rate 100Mbit/s, 100% coverage until 2025,

Most countries will achieve 20% FTTH penetration in next five years and 50% FTTH penetration is not likely before 2020. The most realistic plan for reaching the target 100Mbit/s data rates in short period is to exploit VDSL.vector technology ITU G.993.5.

3 VDSL vectoring challenges

VDSL vectoring is improvement of existing VDSL2 which applies far-end crosstalk cancellation to increase data rate or distance range [3], [4]. Typical performance is 100Mbit/s on 400m loops. Data rate in comparison with VDSL2 is typically three times higher. The main advantage of vectoring is not only the data rate acceleration but also more predictable capacity calculation based on line length, pair diameter and background noise level. Data rate variations due to unpredictable FEXT are eliminated in comparison with VDSL2. Preliminary laboratory and field tests by different EU operators confirms that minimum data rates for a line length 500 meters are between 60Mbit/s and 100Mbit/s. VDSL with vectoring offers higher data rate and more stable in comparison with standard VDSL2 where FEXT is a major disturbance and can cause unpredictable variations. A highly stable link is very important for IPTV, where consumers do not tolerate any loss.

The main problem is that vectoring delivers the full improvement only where all the pairs in a given cable/group are managed by a single operator. In other case the near end crosstalk is only partly cancelled and residual FEXT from so-called alien disturbers can have a major influence on minimum achieved data rate. The influence of non-vectored pairs varies from pair to pair and the minimum data rate drops down and also becomes more unpredictable as in VDSL2. The problem can be solved by cross DSLAM vectoring, but the technique is not yet standardized. Initial cross DSLAM vectoring implementations are likely among DSLAMs of a single vendor. An average influence of alien crosstalk is reduced when the number of non-vectored lines is small relative to vector group size. System level vectoring can support large groups (100-1000) and includes multiple line cards. The other option is a board level vectoring which applies vectoring only on small number of lines.

Alien-crosstalk can also be cancelled by vectoring, but only in the upstream, where several lines are controlled together [5], [6]. There is no method to cancel the alien-crosstalk in the downstream and the only way is limiting it at its source. The influence of alien crosstalk can be reduced by appropriate dynamic spectrum management (DSM). The best solution is to centralize the DSM function, but the simplest solution is to limit the transmit power and data rate on non-vectored lines. The alien-crosstalk harms vectoring only when alien lines are left completely unmanaged. As an example some laboratory tests shows that alien-crosstalk from only five alien pairs in a 25 pair cable can reduce the data rate for 45%. When properly managed via DSM, non-vectored lines whose data rate is capped at 25Mbit/s only reduce the speed of vectored lines by 5-10% in 99% cases [5]. Restrictions to unbundling from technical reasons are not appropriate.

Alternate solution is to change the unbundling model from physical line unbundling to virtual unbundling, where all transmission equipment stays under a single operator control. Virtual unbundling allows new service providers to access the incumbent´s network via a dedicated virtual link. It is an enhanced bit stream based access and should offer a wide range of speeds, QoS options, prioritization etc. Virtual unbundling is still a work in process and products are currently not available.

There are complementary technologies, which can accelerate vectored VDSL systems. Subscriber cables with two twisted pairs (one quad) are widely available per household, but only one pair is used for DSL transmission. It is possible to double the data rate by bonding both pairs. It is also well known from old analogue telephony that by appropriate signalling two pairs can establish the third so-called phantom line. Phantom mode and bonding two lines together can triple a single vectored line data rate.

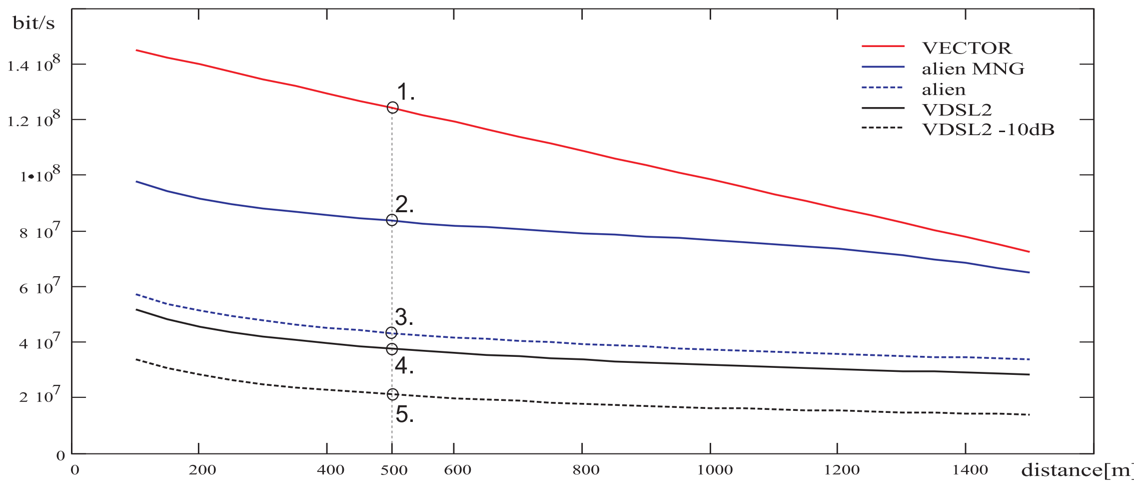

Figure 2. Calculated VDSL2 down-stream data rates for **vectored** 1.FEXT-free, 2.with managed alien FEXT, 3.with unmanaged FEXT and **non-vectored** 4.VDSL2 and 5.caped VDSL2.

4 VDSL vectoring capacity gain

The most important VDSL capacity-range limiting parameters are signal attenuation, far-end crosstalk FEXT and cable ingress noise. Line attenuation model is defined by equation:

$$|H_L(f,d)| = e^{-K_l d\sqrt{f}} \tag{1}$$

Konstant value $K_l = 1.497$ corresponds a typical attenuation 13dB at 1MHz for a 1km cable with a line diameter 0.6mm.

FEXT power sum is rising with a coupling path distance d, and also suffers from attenuation [7]:

$$|H_{FEXT}(f,d)|^2 = |H_L(f,d)|^2 K_{fext} f^2 d \tag{2}$$

Total transmit signal power $P_0 = 14dBm$ is equally shared among sub-channels with a cumulative bandwidth B. Received signal spectrum is defined by equation:

$$S(f,d) = \frac{P_0}{B}|H_L(f,d)|^2 \tag{3}$$

Channel noise model for VDSL2 takes into account FEXT and background white noise:

$$N(f,d) = \frac{P_0}{B}|H_{FEXT}(f,d)|^2 + N_0. \tag{4}$$

FEXT power sum is calculated from FEXT source signal spectrum and from statistical model (2). In VDSL2 capacity calculation only self-FEXT from $N = 24$ adjacent lines is taken into account.

VDSL.vector capacity is calculated with two different channel noise models, for ideal full-vectored system with a background noise level $N_0 = -140dBm/Hz$ and with crosstalk from alien non-vectored lines.

$$N(f) = N_0 + FEXT_{alien}(f) \tag{5}$$

Available data rate r is calculated by equation:

$$r = \eta \int_{band} \log_2\left(1 + \frac{1}{\Gamma}\frac{S(f)}{N(f)}\right) df, \tag{6}$$

with a typical spectral efficiency $\eta = 0.9$ and total SNR offset $\Gamma = 12dB$.

Results of capacity calculation in downstream for VDSL2 and VDSL.vector systems are shown on figure 2. All calculations are valid for VDSL2 downstream link in frequency profile 17. A cable has 25 pairs and in worst case there are 24 self-FEXT disturbers. Curves on figure 2 are explained with noted data rates at distance 500 meters:

1. VDSL.vector ideal FEXT-free capacity at distance 500 meters: r=125Mbit/s,
2. VDSL.vector capacity with managed 8 non-vectored lines. A 20dB alien FEXT reduction is assumed to be achieved by 10dB alien source power reduction and another 10dB by appropriate non-vectored group selection. Note that alien crosstalk reduction for 20dB in the second scenario is based also on assumption that appropriate selection of non-vectored pairs can reduce the near-end crosstalk for 10dB. Pair rearagement is a labour intensive and expensive and such solution is not favored by operators. Ideal FEXT-free capacity at distance 500 meters is reduced on 67%: r=84Mbit/s,
3. VDSL.vector capacity with 8 non-vectored line leaved unmanaged. In the worst case, FEXT power with 8 interferers is reduced only for 3dB and capacity improvement in comparison with non-vectored VDSL2 system is poor: r=43Mbit/s,
4. VDSL2 capacity with 24 self-FEXT interferers at distance 500 meters: r=38Mbit/s,

5. VDSL2 capacity with 24 FEXT interferers after power reduction (-10dB) drops down to r=22Mbit/s.

Described method of alien crosstalk mitigation by a simple power reduction on non-vectored lines demonstrates how it affects both capacities: the vectored lines capacity keeps high, but capacity on non-vectored lines drops down. In practice a power management method should control a minimum non-vectored line data rate.

Note that vectoring capacity gain depends on line distance and background noise level. Vectoring is effective only for short lines and at low background noise. For example, ideal vectoring gain falls down from 3.3 to 2.2 at increased noise level -120dBm/Hz. Ideal FEXT free capacity (1.) at 500 meters falls to 84Mbit/s and capacity with managed alien lines (2.) falls to 77Mbit/s, while other capacities are not affected by background noise. Much higher background noise (-100dBm/Hz or more) is close to FEXT power spectrum density and vectoring makes no sense.

5 The last DSL

After launching the 3G VDSL systems VDSL.vector, the fourth-generation G.fast is on the DSL roadmap. A major part of the FTTH infrastructure costs comes from the last 100-200 meters on the subscriber side and G.fast is proposed to cut this part of the fiber installation costs. Technology is still under discussion, and standard approval is expected in the first quarter of 2014. Capacity improvement is possible by vectoring, loop shortening to the last distribution point and by using much higher spectrum bandwidth than VDSL2.

The system is designed to operate in coexistence with earlier DSL technologies [8]. The start frequency is at the end of ADSL2 or VDSL2 band: 2.2MHz, 8.5MHz, 17.664MHz or 30MHz. Flexible start frequency enables a migration from VDSL2 to G.fast systems. Duplexing in both directions is implemented by time division, which can easily vary downstream and upstream ratio from 90/10, 50/50 to 10/90. G.fast will use DMT modulation method, but with twelve times larger subcarrier spacing than ADSL and VDSL systems. G.fast DMT will use $N = 2048$ sub-carriers, separated by $\Delta f = 51.75kHz$. The total spectrum bandwidth is 104.45 MHz and the number of bits per sub-carrier is limited to 12. G.fast rate performance targets on 24 AWG cables are: 150Mbit/s at 250m, 200Mbit/s at 200m and 500Mbit/s at 100m. Target applications for G.fast are next-generation IPTV for domestic users, small business sites, backhaul for wireless cells and backhaul for WiFi hot spots.

6 Conclusion

Capacity demands are growing very fast and only fiber access network could serve the future trends. FTTH technology is expensive and time consuming to deploy and 50% coverage in EU is not likely before 2020. The most realistic plan for reaching the target 100Mbit/s data rates for almost every EU citizen in ten years is to exploit DSL technology. VDSL.vector technology is already available and G.Fast is most likely the last DSL technology on the way to all-fiber wired access network.

Vectoring delivers the full transmission capacity improvement only where all the pairs in a given cable are managed together. Alien crosstalk harms vectoring only when non-vectored lines are left completely unmanaged. Even for a simple method of alien noise reduction, the result of capacity calculations in this paper demonstrates that it is possible to keep a major part of the vectoring capacity improvement. There are several better methods for supporting vectoring when multiple service providers share the copper cables.

The unbundled local loop (ULL) and vectoring concept could work together even for multiple service providers, but only if they cooperate. Operators and regulatory authorities should find the way for cost-effective and successful VDSL.vector deployment.

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