THE TURBULENT TELECOMMUNICATIONS

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Summary: The paper depicts the rapidly changing scene in the telecommunications arena. It provides an overview of recent key developments in technologies that enable access to broadband Internet, describes the trends in provisioning services on the IP platform and discusses policy, regulatory and market issues stemming out from the new developments in telecommunications.

1. INTRODUCTION

Telecommunications is undergoing profound transformation. In the old golden times, everything was clear: Telecommunication operators were state monopolies and reliable customers for national vendors of equipment. Customers had no choice, services and prices for them were regulated. Now, at the time of rapid developments in the area of telecommunications, entertainment and data transmission and processing, liberalisation and deregulation, investors, network operators, service providers and equipment vendors must ask a question: Quo vadis telecommunications? Convergence of all previously independent media, services and devices is the slogan of the day. But this is a very complicated process shaped by happening in the technology, services, economy, regulation and even politics domains.

In the technology area the first phase of telecommunication revolution – digitalisation has been completed. The second phase – packetisation is in full swing now and will be soon completed by transition of even real time communications such as voice and video to packed-based transmission and switching (Voice-over-IP, IP-TV). Some major telecommunication operators have already committed to this evolutionary path. The main driving force behind these developments is Internet and web-based applications that caused the data to overtake in volume the other means of communication. While in the core networks optical transmission has clearly prevailed with the switching in the optical form just started, the access networks have remained the bottleneck. Here, all technologically feasible forms of signal transmission are finding their place - wireline as well as wireless.

Services and applications, for which the customers are willing to pay, are indispensable to make the networks economically sustainable. However, no single “killer application” has emerged yet although access to Internet in general seems to be the driving force. Most likely, instead of a single major service, there will be a host of IP-based services from which customers will be able to choose according to their preferences. Multiple-service provision is clearly the trend of the day.

Most countries have already made a political decision to liberalize the telecommunications sector. To enable competition in this area resulting in reduction of prices and increase in choice of services, activities of the former state monopolies (incumbents) are regulated to give a fair chance to alternative operators (new entrants to the market) to compete with the incumbents.

Good telecommunications infrastructure and services in general, and widely available broadband Internet access enabling IP-based services in particular, is regarded as key driver of the overall prosperity and well being of the economy of any country. Therefore, main focus of this paper is on underlying technologies that enable to achieve this goal, namely on the access part of the telecommunication infrastructure, trends in provision of services and the associated regulatory and policy issues.

2. RECENT TECHNOLOGICAL TRENDS – THE TECHNOLOGY PUSH

A network architecture is emerging, where the network is divided into a rather transparent core (long-haul, long distance) employing optical fibres and switches doing rather simple signal manipulation encircled by intelligent (multiplatform) electronic edge devices consolidating the many signal formats coming from and outgoing to the access part of the network. While optical transmission has firmly established itself in the core network, all possible kinds of transmission media are finding application in the access network.

Telecommunication network customers interests are turning to the versatile, content-rich public Internet. Telecommunication operators, whether fixed or mobile, are responding to this trend by deploying broadband access. Therefore, we shall mention the core networks only briefly focusing our attention to the access part of the telecommunication networks.

2.1. Core networks

Currently, the major development in the core network is introduction of optical switching. At present, only circuit switching (Optical Add/Drop

Multiplexers – OADMs and Optical Cross Connects – OXCs) of consolidated (at the edge) high-speed data streams has found its way into core networks. Optical switching of short packets at Gb/s and higher bit rates is still a subject of research. A compromise between optical circuit switching and optical packet switching – optical burst (packets at least a few microsecond long) switching – is also being investigated for some time but not commercially employed yet.

Satellite communication over long distances is indispensable in television and data distribution, in covering large sparsely populated areas and in communication with moving objects. It has found its niche in connecting the customers over the Internet especially to very remote servers.

2.2. Access networks

The scenery is much more complicated in the access networks. They are the main battlefield with fierce competition among several wireline and wireless technologies.

There are three wireline contenders to realize access networks:

- Twisted copper pairs (TCPs) mostly owned by incumbent operators enabling to realize various kinds of Digital Subscriber Lines (xDSL)
- Cable television (CATV) distribution networks
- Optical fibres
- Low voltage electric power supply lines connecting customers to electricity suppliers.

Asymmetrical DSLs (ADSLs) on twisted copper pairs provide the most common method for providing broadband to locations within a few km of a local office. They have the potential to deliver 8 or more Mbit/s to many consumers living close to an exchange and therefore to support future services such as TV over IP. CATV too is well suited for urban areas, and is very competitive with ADSL. Optical fibres are the most promising transmission media for connecting the end customers to the public network since they provide virtually limitless bandwidth. Broadband over power supply lines (Power Line Communication, PLC) has the promise of low cost because it both exploits copper that is already deployed and offers reasonably high speed. But costs for CATV networks and xDSLs are already low due to the installed volumes so it will be tough for optical fibres to supersede the two established broadband access media and PLC to gain a market foothold.

In the wireless world, that includes any type of signal transmission without employing transmission lines, the options of realizing access networks are as follows:

- LAN-based technologies such as WiFi (Wideband Fidelity) for short range access in "hotspots"
- Wireless network covering metropolitan areas or regions up to several km wide such as WiMax
- Cellular networks for wide area mobile terrestrial communication such as GSM, CDMA and UMTS networks
- Terrestrial Digital Video Broadcast networks (DVB-T)
- Satellite networks.

The last two types of wireless access networks may use wireline return channels.

Wireless solutions for the access network appear to be the lowest cost solution for green-field regions that have little copper or cable to date. WiFi lacks the bandwidth to scale up to the capacities needed for real time video services, but the newer WiMax technology with WiFi will offer sufficient capacity to deliver typical commercial services, and it could support the leap forward in ICT capability needed in the future for small and medium enterprises. However, its limited range diminishes its attractiveness.

2.2.1. Wireline access networks

In quest of leveraging the ubiquitous twisted copper pairs connecting the customers to, as a rule, the incumbents´ telephone networks, sophisticated modulation methods have been developed that enable to use these basically narrow band transmission lines for broadband communication with the speeds theoretically up to 100 Mb/s over the distances from about 100 m (at tens of Mb/s data rates) up to several km (at Mb/s or less data rates). For this high-speed digital transmission, the frequency band above the 4 kHz voice band is used extending over 1 MHz. This method of high-speed data transmission over the TCP subscriber lines is generically called xDSL [1]. ADSL means asymmetrical (with the upstream data rate much lower than the downstream), while VDSL means very high speed transmission. Over the time, several DSL technologies have been developed, see Table 1.

Asymmetrical Digital Subscriber Line (ADSL)

In ADSL, as a rule, Discrete Multi-Tone Modulation (DTM) is used. The digital stream organized in frames is transmitted simultaneously in DTM format over many Multi-valued Quadrature-Amplitude-Modulated (M-QAM) sub-channels located above 25 kHz frequency. The parameter M can be changed adaptively according to the quality of the line sub-channel. The frame formation includes scrambling, redundant Reed-Solomon encoding, interlacing and a mechanism of prioritizing the channels joining the multiplexer.

Three factors have a negative impact on the band and reach of a digital transmission through the same line:

- The quality of technical infrastructure of the subscriber's line

- Propagation losses depending on the sub-channel frequency and the length of the line
- Crosstalk between the copper pairs.

Several variations of xDSL have been developed:

ADSL2 offers increased rate (up to 12 Mb/s upstream and 1 Mb/s downstream) and reach, more advanced line diagnostics, power enhancements, rate adaptation and bonding of lines for higher data rates.

ADSL2+ doubles the bandwidth used for downstream data transmission by utilising a frequency spectrum up to 2.2 MHz achieving the maximum theoretical data rates of 24 Mb/s for downstream and 1.5 Mb/s for upstream.

*VDSL (*Very-high bit rate DSL) promises to deliver up to 55 Mb/s to residential customers and up to 16 Mb/s in the opposite direction. VDSL extends the Fibre-To-The-Neighborhood (FTTN) or Fibre-To-The-Curb (FTTC) optical access networks to end users. VDSL potentially enables broadband applications such as interactive and Internet TV, VoIP, and multi-channel HDTV.

VDSL2 utilizing a bandwidth of 12 MHz can achieve 55 Mb/s downstream and 30 Mb/s upstream over the distance of up to 3 km. The more advanced alternative using 30 MHz bandwidth can deliver up to 100 Mb/s upstream/downstream (symmetrical) over short distances (300-500 meters). VDSL2 is compatible with ADSL, ADLS2, ADSL2+. It also supports Quality of Service (QoS) which is critical for applications such as “triple-play”. VDSL2 is viewed as the ultimate DSL standard, which in conjunction with FTTx technologies provides sufficient bandwidth for the years to come and its adoption is ramping up rather quickly.

Tab. 1. Achievable reach versus transmission rate for different types of DSL access lines

	Approx. down/upstream bandwidth (Mb/s)				
Reach→	0.5 km	1 km	2 km	3 km	5 km
ADSL	8/1	7.5/1	6.5/1	3/0.5	0.5/0.1
ADSL2	10/1.1	9/1.1	8/1	3.5/0.5	0.6/0.1
ADSL2+	19/1.1	15/1.1	10/1	4/0.75	0.6/0.1
VDSL	40/20	20/7	0/0	0/0	0/0
VDSL2	60 (300m)	22/1.1	10/1	4/0.75	0.6/0.1

CATV networks

The CATV network operators have enhanced their networks by making them two-way, equipping their customers by suitable modems (as a rule, of the standardized DOCSIS type) and by placing appropriate equipment in their head ends enabling high speed data transmission in both directions utilizing the high bandwidth available in these networks. However, CATV network is an environment shared by many customers which can be a performance limiting factor especially of the return channel. Therefore, for the return channel, more and more bandwidth of the lower part of the CATV frequency spectrum is being allocated approaching 100 MHz while for the forward communication (in the direction toward the customers) several TV channel are aggregated for data transmission required by internet-based services. To further enhance the CATV networks for this kind of application and to get rid of the many expensive two-way electronic amplifiers, optical fibres are being deployed in the primary part of CATV networks leaving only their passive parts to be shared by no more than a few hundred customers. These HFC (Hybrid Fibre Coax) networks are at present the main competitors of the xDSLs in the access networks.

Optical fibre access networks

Optical fibres, regarded as the ultimate transmission medium to provide true broadband access, are at last finding their way to end customers. Japan, Korea and recently USA have already installed millions of fibre links to end users. Passive Optical Network (PON) architectures [2] are used in the access part of communication networks employing optical fibres and passive splitters. Depending on how close the fibres are brought to end users there are several alternatives of deploying fibre in the access networks:

- Fibre To The Node or Neighborhood (FTTN) from which a kind of xDSLs emanate to end customers
- Fibre To The Curb (FTTC) where Optical Network Units (ONU) with opto-electronic converters are located at the curb connecting end customers to the network thorough copper pairs
- Fibre To The Building (FTTB) with ONUs situated at the pedestal of multi-dwelling or multi-tenant buildings interconnecting with passive copper pair in-house networks
- Fibre To the Home (FTTH) with ONUs located in end users homes or businesses.

PONs are based on Time Division Multiplexing/Time Division Multiple Access principles. In the downstream path this topology allows data to be distributed by broadcasting them through passive fibre splitters to all end users at a wavelength equal to 1490 nm. There, the relevant data are collected by inspecting packet/cell identifiers. The upstream operates at 1300 nm and is controlled by the head end that assigns transmission windows to each customer.

The first Broadband PON (B-PON) recommendation (1998) is ATM-based and has been extensively deployed. B-PON systems can be either symmetrical (both upstream and downstream operate at the same link rate, either 155 Mbit/s or 622 Mbit/s) or asymmetrical (622 Mbit/s downstream and 155 Mbit/s upstream). In 2003, a modification to the B-PON standard upgraded the upstream rate to 1.244 Gbit/s.

Following B-PON, the next generation of PON protocols is the Gigabit capable PON (G-PON) that allows both ATM cells and variable-length packets to be transmitted through the same PON. Any packet or frame-based service can be transported over PON including Ethernet and TDM services. G-PON offers downstream line rates of 1.244 Gbit/s and 2.488 Gbit/s and upstream line rates of 622 Mbit/s, 1.244 Gbit/s or 2.488 Gbit/s, quality of service and forward error correction.

E-PONs are based on the Ethernet IEEE standard, they can take advantage of the economies-of-scale associated with Ethernet equipment, which is already extensively used. They provide 1 Gb/s in both directions and forward error correction. However, they are less efficient than G-PONs.

Table 2 compares the main features of the PON technologies. Wavelength Division Multiplexing (WDM) can be employed in PONs to increase the overall throughput of the networks.

Tab. 2. Comparison of main PON technologies

xPON	**B-PON**	**G-PON**	**E-PON**
Standard	ITU-T G.983	ITU-T G.984	IEEE EFM
Max. downstream	1.25 Gb/s	2.5 Gb/s	1 Gb/s
Max. upstream	622 Mb/s	2.5 Gb/s	1 Gb/s
Max. splitting ratio	1:32	1:128	1:16
Payload format	ATM	ATM, TDM, Ethernet	Ethernet
Max. distance	20 km	20 km	20 km

Power line communication

The power line communication (PLC) is a relatively new way of accessing the telecommunication networks. By using sophisticated modulation and coding methods over the last part of the electric power distribution networks, several Mb/s data can be extracted from the ubiquitous electrical outlets. PLC gives a chance to power utility companies to access the end users and provide them telecommunication services in competition with other telecommunication operators. The problem not yet completely solved is potential interference of these systems with wireless services.

2.2.2. Wireless access networks

Application of wireless technologies in the access networks is developing even more dynamically than of the wireline ones.

Wireless access to Internet has basically developed in four directions:

1) Based on extensions to GSM cellular networks. Examples are GPRS and EDGE. The capability of these systems is limited by technical parameters of the GSM networks.
2) Based on wireless technologies specially designed for that purpose, for example, the family of IEEE 802.11 products followed by UMTS and recently WiMax; CDMA technology limited to data transmission can also be used for accessing the Internet.
3) Based on digital terrestrial TV broadcast networks (DVB-T).
4) Based on satellite broadcast networks (DVB-S).

Access to the Internet over cellular networks

Table 3 shows the maximum achievable bit rate of the wireless technologies for data transmission over GSM, CDMA and UMTS cellular networks.

Tab. 3. Basic comparison of technologies for data transmission over cellular communication networks

Wireless technology for data transmission	**Theoretical max. transmission bitrate**
GPRS	171.2 kb/s
EDGE	473.6 kb/s
CDMA	2.48 Mb/s
UMTS	1 - 2 Mb/s
HSDPA	14.4 Mb/s

The most important wireless technologies for data transmission over cellular networks including those quoted in Table 3 can be briefly described as follows:

- GPRS (General Packet Radio Service): an overlay on the GSM network, designed to enable data transmission to and from mobile phones using the WAP protocol.
- EDGE (Enhanced Data rates for Global Evolution): an auxiliary service for mobile phones. It is an improvement of GPRS.
- CDMA (Code Division Multiple Access): Operating e.g. at 450 MHz it can cover large areas around the base stations.
- UMTS-TDD and UMTS-FDD: further extensions to EDGE operating in frequency bands around 872 MHz and 1.9 GHz.
- HSDPA (High Speed Downlink Packet Access): A packet-based data service in W-CDMA (Wideband CDMA) downlink with data transmission rates up to 8-10 Mb/s. It increases the data rates of UMTS-FDD.

Broadband Internet access over 802.11 (WiFi) and 802.16 (WiMax) networks

Although originally intended as a wireless option for local area networks (LANs), now WiFi is sometimes used as access technology, in some cases even for outdoor users or for connecting to core cellular networks. Recently, one of the four bands of 802.11a has been specifically reserved for that purpose in the USA.

Table 4 shows the two basic parameters of the wireless technologies for data transmission over the 802.11 and 802.16 networks. In practice, the transmission rates attainable may be much lower depending on the terrain, distance and the number of customers simultaneously connected to the base station.

Tab. 4. Basic comparison of 802.16 and 802.11 wireless technologies for data transmission

Wireless technology for data transmission	Theoretically achievable maximum transmission rate	Maximum range
802.16d (2004 - WiMax)	75 Mb/s	50 km
802.16e (Mobile WiMax)	4 Mb/s	up to 1 km
802.11b (WiFi)	11 Mb/s	100 m
802.11a (WiFi)	54 Mb/s	50 m
802.11g (WiFi)	54 Mb/s	100 m

The wireless technologies for data transmission quoted in Table 4 can be briefly described as follows:

- 802.16d (2004-WiMax) offers better security, QoS and coverage of larger areas in cities (range of 2 to 5 km) as well as rural areas (with directional antennas reach up to 50 km) than WiFi. It is designed for connection with stationary users. The low latency allows video streaming and VoIP services.
- 802.16e (Mobile WiMax) is aimed at mobile customers and is still at an early stage of development.
- 802.11 is a family of protocols, all intended for connections of stationary or quasi-stationary customers over short distances (50 to 100 m with omni-directional antennas), with relatively high speed (11 to 54 Mb/s).

To meet the need of providing services over broadband access and of merging diverse network services a concept of Next-Generation Network (NGN) has been developed over the past few years that would integrate a series of networks, fixed and mobile, and support a flexible IP-based platform for service delivery [3].

3. THE SERVICES PULL

While the landscape of telecommunications technologies is diverse enough and varying fast, developments in the area of services is even more dramatic and difficult to predict.

Any of the single-media based service (voice, sound, still and moving pictures, text, data) can be realized in several ways and provided by different competing service providers. Convergence is the continuing trend in the services area as it is in the networks and devices. Multimedia communication has become commonplace and offering bundled services such as “triple play” (voice, video and data) is a must for service providers these days. The basic voice and video services traditionally provided by the telecommunication and by broadcasters and CATV operators, respectively, are being targeted by alternative service providers.

Availability of access to broadband Internet has spurred development of a host of IP-based services (Fig. 1). Particularly popular has become provision of voice services over IP (VoIP) with IP TV emerging. Since access to Internet can often be provided in a particular place by several network operators, these have to compete for the same customers encroaching on each others traditional market, e.g. CATV operators offering VoIP and telecommunication operators providing TV services. Thus, the boundaries between traditional markets are getting blurred.

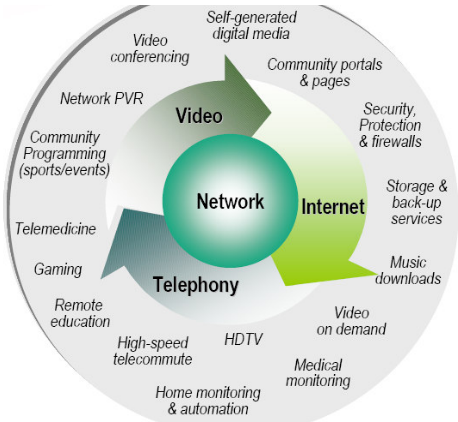

Fig. 1. Landscape of e-services

Availability and utilization of data-based services (e-services) provided over the Internet, such as e-government, e-health, e-learning, e-business, etc., have become important factors in many areas of advanced societies. Therefore, securing access to Internet to as many of its citizens as possible has become these days an important priority for any government.

IP platform and deregulation provides an opportunity for service providers to develop and offer new services to differentiate themselves from their competitors. However, no service has emerged yet as a “killer” application of the new information infrastructure. It seems that customers will demand a rich collection of services to choose from according to their needs.

Of growing importance is the peer-to-peer communication over the Internet where the content is created by the end users themselves.

4. MARKET, REGULATORY AND POLICY ISSUES

Because of growing importance of telecommunications infrastructure for economy of any country, governments are striving to create friendly regulatory environment to encourage investors entering this field again after their stampede a few years ago. Regulatory action can make a significant difference to the business case. In some countries governments have played a key role in the promotion of building advanced infrastructure such as optical FTTH access networks by providing direct subsidies for the projects as a tool of industrial policy.

But public funding is a fundamental policy issue. Many regional and public authorities in Europe have launched or are currently planning broadband access projects, some have already realized such projects driven by local initiatives. In general, these initiatives are welcome as new means of enhancing the telecommunication infrastructure in the liberalized environment, promoting economic development, improving quality of living, education and retaining skilled workforces. However, realization of these projects is being hampered because of legal uncertainty over the applicability of state aid rules and public funding. Because of that, the projects are considered on a case-by-case basis. To protect their investment, traditional telecommunication operators, by lobbying the policy makers, strive to impose restrictions on the municipalities planning to build free city-wide broadband access to Internet. This is a hot issue for the policy makers to resolve. Are the local initiatives in the public interest or will they distort the market competition?

To increase regulatory certainty it would help if the regulatory authorities provided clear guidance on state aid, distinguished between new and old (pre-liberalisation) investments, limited ex-ante regulatory intervention to "metallic local loops", mandated duct sharing and ensured that civil works are co-ordinated. In some cities it proved useful to have built "open networks" or "equal access networks" available to multiple independent service providers. This kind of investment of public money might not be considered as direct state aid. It certainly would be done in public interest. Also, since the passive infrastructure has a much longer life cycle than its active elements, depreciating its cost should not be considered a subsidy.

In countries where competitive access platforms already exist, the competition itself has been a significant driver in the deployment of FTTH. In Europe, the main competitive platforms for broadband Internet access so far are xDSL and CATV networks, although in some Central European Countries, wireless access also plays an important role in providing access to Internet.

For regulators, there are two key parameters to assess in determining if platform for competition exists:

- Homes passed coverage, and
- Technical capability of the network (capacity).

Deployment of optical fibres to end customers as a future-proof solution of broadband access to Internet deserves special attention. It allows implementation of completely new services and applications superior to the existing ones that lack the bandwidth. But there is a key risk for potential investors: Could a regulator mandate access to this FTTH infrastructure to a competitor in order to increase competition? Absence of clear answer to this question in the European Union deters major investors from building FTTH access networks since they feel their investment would not be adequately protected. This key barrier has already been removed by the FCC regulator in the US.

5. CONCLUSIONS

The major trends in the field of rapidly changing unsettled telecommunications can be summarized as follows:

- Convergence of fixed and mobile networks is continuing unabated
- Fixed operators are focusing on building out networks in order to deliver converged services
- Mobile operators are beginning to offer, in addition to voice, high-speed data services on their next generation networks
- IP protocol is emerging as the common platform for transmission of signals and provision of telecommunication services
- Provision of multimedia communication is becoming a norm for competing service providers
- Regulation to create competitive environment resulting in lowering prices for services is high on political agenda of all governments.

There is a risk for every country to be left behind in reaping the benefits of having advanced telecommunication infrastructure that makes a significant impact on productivity/industrial development, etc., unless it:

- takes necessary steps to establish clear platform for competition
- removes regulatory uncertainty regarding FTTH investments
- clearly documents the rules regarding the use of state aid.

Involvement of central as well as local authorities in supporting development of broadband access infrastructure in deprived areas is unavoidable in order to prevent "digital divide".

What is ahead for telecommunications? Continuous change…

REFERENCES

[1] V. B. Lawrence et al.: *Bell Labs Tech. Journal, Vol. 1, No 1, Summer 1996*

[2] G.983.x and G.984.x series of ITU-T standards

[3]Ch.-S. Lee, D. Knight: *IEEE Commun. Magazine, October 2005, 34.*