WHITE PAPER:

COMPARISON OF ACCESS TECNOLOGIES

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GLOSSARY AND ACRONYMS

3G	Third Generation Mobile Phone Networks
ADSL	Asymmetric Digital Subscriber Line
AON	All Optical Network
BER	Bit Error Rate
BPL	Broadband Power Line
CAIS	Common Airborne Instrumentation System
CAPEX	Capital Expenditure
CDMA	Code Division Multiple Access
CISPR	International Special Committee on Radio Interference
CPE	Customer Premise Equipment
DHCP	Dynamic Host Configuration Protocol
DOCSIS	Data Over Cable Service Interface Specification
DSLAM	Digital Subscriber Line Access Multiplexer
DVB	Digital Video Broadcasting
EFM	Ethernet in the First Mille
EMC	Electromagnetic Compatibility
ETI	European Telecommunications Institute
ETSI	European Telecommunications Standards Institute
EU	European Union
FCC	Federal Communication Commission
FM	Frequency modulation
FSO	Free Space Optics
FSP	Free Space Photonics
FTTB	Fibre to the Building
FTTH	Fibre to the Home/Curb
FTTK	Fibre to the Kerb
FWA	Fixed Wireless Access
GHz	Gigahertz
GSM	Global systems for mobiles
HDSL	High Speed Digital Subscriber Line
HE	Head-End
HFC	Hybrid Fibre Coax
ICT	Information and communications technology
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMT	International Mobile Telecommunications
IRED	IR-Emitting Diodes
ISDN	Integrated Service Digital Network
ISP	Internet Service Provider
ITU	International Telecommunications Union
Kbps	kilobits per second
LAN	Local Area Network
LED	Light-Emitting Diodes
LMDS	Local Multipoint Distribution Service
LV	Low Voltage

MHz	Megahertz
MMDS	Multichannel Multipoint Distribution Service
MPEG	Moving Pictures Experts Group
MSO	Multiple System Operators
MV	Medium Voltage
NTSC	National Television System Committee
OFDM	Orthogonal Frequency Division Multiplex
OLT	Optical Line Terminal
OPERA	Open PLC European Research Alliance
OPEX	Operating Expenditure
PAL	Phase Alternating Line
PLC	Power Line Communications
PON	Passive Optical Network
POP	Point of Presence
POTS	Plain Old Telephone Service
PPPoE	Point-to-Point Protocol over Ethernet
PSTN	Public Switched Telephone Network
PUA	PLC Utilities Alliance
PVR	Personal Video Recorder
QAM	Quadrature amplitude modulation
QoS	Quality of Service
RF	Radio Frequency
ROI	Return of Investment
SECAM	Séquentiel Couleur avec Mémoire
SME	Small and Medium Enterprises
SOHO	Small Office and Home Office
TDMA	Time Division Multiple Access
VDSL	Very High Speed Digital Subscriber Line
VLAN	Virtual Local Area Network
VoD	Video on Demand
VoIP	Voice Over Internet Protocol
WiFi	Wireless Fidelity
WIMAX	Worldwide Interoperability for Microwave Access
WLL	Wireless Local Loop
xDSL	Digital Subscriber Line

REFERENCES

[1] [IBV04] Reference introduced by Author Iñigo Berganza Valmala in 2006

[2] The Struggle for C-band, *Via Satellite*, August 1, 2007. http://www.satellitetoday.com/via/cover/18648.html

[3] Xavier Carcelle, An Introduction to Powerline Communications, February 15, 2007, http://www.oreilly.com/pub/a/etel/2007/02/15/an-introduction-to-power-line-communications.html.

[4] White Paper on Power Line Communications (PLC) and its Impact on the Development of Broadband in Europe, Arthur D'Little, November 25, 2002. http://www.pua-plc.com/files/upload/Whitepaper2002.pdf

[5] White Paper on Power Line Communications (PLC) 2004, Arthur D'Little, November 12, 2004. http://www.pua-plc.com/files/upload/041021__Whitepaper_PLC_2004.pdf

[6] Julio Berrocal, *et al.*, "Redes de Acceso de Banda Ancha. Arquitectura, prestaciones, servicios y evolución" (in Spanish), Ministerio de Ciencia y Tecnología, 2003.

[7] Sathya Rao (IST Powernet Project), "Use of ubiquitous powerline infrastructure for providing broadband access to bridge the ICT divide", Bridging the ICT divide workshop, Brussels, March 22, 2006 [on-line]. Available: http://www.ist-powernet.org/.

[8] DSS9010 200 Mbps Powerline Communications IC for AV Home Networking, Product Brief, DS2 [online]. Available: http://www.ds2.es.

[9] SecureView SBOX - S-Box Powerline Video Transmission Set [online]. Available: http://www.asihome.com/ASIshop/product_info.php?products_id=614.

[10] Slingmedia Case Study, Powerline Networking Communications, April 17, 2006 [online]. Available: http://www.powerlinenetworking.co.uk/.

[11] Telefónica Imagenio [online]. Available: http://www.telefonica.es/tol/imagenio.html.

[12] PL-RJ45-85, PL-RJ45-200, and PL-USB, Ovislink Powerline Products Catalog [online]. Available: http://www.ovislinkcorp.es/index.php?seccion=productos&id_cat=54.

[13] Robert Valdes, How Broadband Over Powerlines Works [online]. Available: http://computer.howstuffworks.com/bpl.htm.

[14] Yoshinori Mizugai and Masahiro Oya, World Trends in Power Line Communications, Technical Report, Mitsubishi Electric ADVANCE, vol. 109, pp. 5-7, March 2005.

[15] “The Amperion Connect™ system”, Amperion, Inc. [online]. Available: http://www.amperion.com/.

[16] C. H. Jones, “Communications Over Aircraft Power Lines”, in Proc. 2006 IEEE International Symposium on Power Line Communications and Its Applications, pp. 149-154, 26-29 March 2006, Orlando, FL.

[17] Y. Maryanka, “Wiring reduction by battery power line communication”, in Proc. Passenger Car Electrical Architecture IEE Seminar, pp. 8/1 - 8/4, 21 June 2000.

[18] http://www.smartbridges.com/.

[19] http://www.wirevolution.com/2007/09/07/how-does-80211n-get-to-600mbps/

[20] http://www.ieee802.org/16/tgm/

[21] http://grouper.ieee.org/groups/1901/

1 PURPOSE

The purpose of this document is to review and assess the main technologies that are used for broadband access. Of course, the strengths and weaknesses of OPERA PLC technology are compared directly to other technologies. The objective is not to deeply analyze the architecture, frequency plans, modulations, distances, etc. of the different technologies, but a brief summary of each one is presented in order to be able to compare them.

Additionally some test cases are analyzed in order to study the possibilities of combination of the access technologies with PLC.

2 INTRODUCTION

The new services demanded by the broadband community require in the order of 15 to 20 Mbps of bandwidth for end users. Depending on the environment conditions, there are several technologies that can reach these capabilities but each one has its own limitations (in terms of bandwidth, reliability, coverage or cost). Besides that, there are other parameters such as delay, jitter, etc. that can affect the quality of service.

The increasing competition in the broadband service market is forcing the suppliers to offer mixed services of data, voice and video in a single connection and it is necessary to test the capabilities of the most significant technologies that exist in the market to meet this demand.

PLC is a very interesting technology that can be the most competitive solution depending on the influence factors, as explained in this document.

3 EXECUTIVE SUMMARY

There are many technologies that can give you the access to broadband services. Depending on the particular condition of your location, your needs, the telecommunication infrastructure available, etc. the selection of the technology that better fits to every case can change significantly.
From dial-up Internet connectivity to broadband access connectivity, several decades have happened and nowadays the network infrastructure, the new demanded services and the security aspects are the drivers of the growing of this market.

The list of demanded services are very extensive (email; E-banking; E-Government; E-Shopping; Multi-PC, printer, network hard drives; Content/Firewall parental controls; Education; Telecommuting, …) and every one with specific requirements for the network that supports them.

In this document we review the main technologies that can be used for broadband access, classifying then in two main groups:

1. FIXED LINE TECHNOLOGIES
   - Hybrid Fiber Coax: Cable TV & Cable Modems
   - Digital Subscriber Line (xDSL)
   - Fiber to the Home/Curb
   - Powerline Communications (PLC): this point includes a brief summary of its standardisation process

2. WIRELESS TECHNOLOGIES
   - Microwave links
   - Multichannel Multipoint Distribution Service (MMDS)
   - Local Multipoint Distribution Service (LMDS)
   - Free Space Optics (FSO)
   - Wireless Fidelity (WiFi)
   - Worldwide Interoperability for Microwave Access (WiMax)
   - Satellite
   - Mobile Phone Networks (2G-3G)

In the next two tables appear the main characteristics of these technologies:

Technology	Simplicity of deployment	Spectrum Usage	Capacity Shared?	Symmetry	Capacity	Max Range	Strengths	Weaknesses
FIXED/WIRED LINE								
HFC	Easy if a cable TV network already exists. Expensive if it is necessary to deploy the network	5-1000 MHz, 6-8 MHz/channel	Yes	Asymmetric.	USA: 3 - 4 Mbps Canada: up to 10 Mbps UK: 1 - 8 Mbps France: up to 100 Mbps Switzerland: up to 6 Mbps	Up to 100 km using amplifiers	Uses existing cable TV networks	Limited bandwidth and asymmetric
ADSL	Easy where it can be used the existing POTs	Up to 1.1 MHz	No	Asymmetric.	From 1,5 Mbps (5.4 km) to 12 Mpbs (300 m)	Up to 5.4 km	Uses existing POTs	Distance sensitive, asymmetric and distance sensitive
VDSL	Easy where it can be used the existing POTs	Up to 1.1 MHz	No	Asymmetric	From 13 Mbps (1.3 km) to 52 Mpbs (300 m)	Up to 1.3 km	Mainly uses existing POTs	Bandwidth is very distance sensitive. Requires fiber feeds
ADSL2+	Easy where it can be used the existing POTs	Up to 2.2 MHz	No	Asymmetric	From 7.5 Mbps (2.7 km) to 26 Mpbs (300 m)	Up to 2.7 km	Uses existing POTs	Bandwidth is distance sensitive
PLC	Easy. No new wiring needs.	1-30 MHz	Yes	Symmetric	200 Mbps shared medium 2 - 4 Mpbs per user	Up to 3 km in Medium Voltage Up to 200 m in Low Voltage	Uses existing power grid	No standards available
FTTH	Difficult. Requires new fibre access network overlay	T Hz	PON: Yes P2P: No	Symmetric	Up to 1 Gbps per channel per fibre	20 km	Very high bandwidth	Expensive deployment of the network

Table 1. Summary of characteristics. FIXED LINE

Technology	Simplicity of deployment	Spectrum Usage	Capacity Shared?	Symmetry	Capacity	Max Range	Strengths	Weaknesses
WIRELESS								
Microwave	Difficult. LOS needed	2, 4, 6, 21.3 –23.6 GHz > 40 GHz UHF(Licensed)	Yes	Symmetric	Up to 155 Mbps per Link	5 km	Quick setup	LOS Point to Point
LMDS	Difficult. LOS needed	28 – 31 GHz (Licensed)	Yes	Symmetric	Up to 155 Mbps per Link	4 km	Point to multipoint Large capacity	LOS Not standardized
MMDS	Difficult. LOS needed	2.1 – 2.7 GHz (Licensed)	Yes	Symmetric	Up to 10 Mbps per BE	100 km	Point to multipoint NLOS and long range	Low capacity Not standardized
FSO	Difficult. LOS needed	Infra-red THz region of RF spectrum (Unlicensed)	Yes	Symmetric	Up to 2.5 Gbps per link	4 km	Low setup cost Unlicensed spectrum	LOS Performance is weather sensitive
WiFi	Easy for LAN environment	2.4, 5.7 GHz (Unlicensed ISM bands ISM: Industry, Scientific and Medical)	Yes	Symmetric	Depending on standard: 2, 11, 54 Mbps	100 m	Ethernet compliant. Standardize.	For LAN applications only Security
WIMAX	Easy. NLOS needed.	2 to 11 GHz (licensed) 10 to 66 GHz (unlicensed)	Yes	Symmetric	Up to 70 Mbps	Up to 50 km	NLOS to be standardized	Practical bitrate2 Mbps NLOS limited to 1 – 2 km
Satellite	Easy but expensive	Ku-, Ka-,C-, L and S-band 1.5~3.5, 3.7~6.4, 11.7~12.7, 17.3~17.8, 20~30 GHz(Licensed)	Yes	Asymmetric	Up to 155 Mbps downlink	1000 - 36.000 km	Large coverage Suitable for multi cast applications	Expensive to build Limited capacity per subscriber
3G	Easy.	1.92 – 1.98 GHz 2.11 – 2.17GHz	Yes	Symmetric	Up to 2 Mbps per mobile	Mobile Coverage area	Mobile terminals Ride on existing cellular infrastructure	Costly spectrum Limited applications

Table 2. Summary of characteristics. WIRELESS

Additionally, some possible test cases are studied in order to know the possibilities of integration between PLC and other access technologies.

PLC + WIMAX
PLC + WLAN
PLC + xDSL
PLC + SATELLITE
PLC + UMTS

4 WHAT IS BROADBAND

4.1 History

Significant migration of domestic Internet connectivity from dial-up to broadband started in the late '90. Business users were able to get broadband access using T-1 or T-3 lines before this date, but prices were to expensive to be affordable by end users. Moreover, T-1 lines are “leased lines” and this kind of connectivity is not designed for the end-user market.

The first broadband access using standard dial-up lines were proposed by some new comer ISP in 1994-1995. The trick was to group multiple dialup lines (PSTN) in a virtual trunk by using the “PPP MultiLink” feature of some devices. However, due to the technology used, it was not possible to get a constant data rate.

Integrated Service Digital Network (ISDN) was the first robust dial-up access technology to bring broadband to end users. The specifications of ISDN basic rate (BRI) give the ability to get 2*64Kb/s, with constant data rate, per access. The ISDN channel bonding feature allows multiple 128 Kb/s access per end user.

ISP started to provide ISDN services to their customers by 1995-1996. Some countries like Germany were (and still are) heavy ISDN users.
As a dialup technology, ISDN's main drawback is the local loop fees. In some contries (such as France) local calls were not free, limiting the end users in the usage. This was one of the main brake in the broadband-over-isdn widespreading in these countries.

The ISDN protocol proposes another access type: PRI (Primary Rate Interface). This access can give up to 2048 Kb/s data rate. The primary rate can be fractionned into n * 64 Kb/s channels. Then, it is possible to choose the data rate, such as 256, 512, 1024 Kb/s, and easily upgrade the data rate when needed whithout changing the physical link.

In 1995, videotron, a canadian cable TV company, was one of the first ISP to offer Internet broadband over coax. The american market then embrassed this technology as cableTV network is installed almost everywhere in the US cities. Company such as ComCast provide both CableTV and broadband Internet access.

In France, the first trial took place in 1996 and the roll-out started in 1998 with France

Telecom and Lyonnaise Cable services.

In the late '90, broadband access in Europe was poor, compared to what North America was able to deliver with the CableTV technology, in terms of penetration, coverage and data rate.

In order to get these market shares, some satellite operators (Eutelsat) in Europe started to provide broadband access over satellite.
The common service was based on a terrestrial return channel: the outbound traffic used a dial-up connection, while inbound traffic used the satellite path.

The biggest drawback with broadband access link is the latency. Some services such as VoIP are very hard to provide with high latency.

The BPL (Broadband Power Line), a technology using power grid to transport data packets, is first deployed in Germany in 1998. The service proposed a 1Mb/s broadband Internet access.

In 1999 both Japan and Italy claimed to be the first country deploying FTTH services for end-users. However, Italy stopped deploying FTTH as xDSL technologies was cheaper to roll out. Japan is still mass-deploying FTTH and Asia is now the part of the world where FTTH is widely available.

After the first trial, aDSL technology is considered to be heavily rolled out in 2000 and 2001, worldwide.

In the following years (2002-2003) several countries in Europe discovered the telecom deregulation, allowing unbundling of the copper lines. Thus, alternative Telco can focus on DSL market by using the local loop, and propose broadband access combined in triple-play services.

With the growing roll out of FTTH in Asia, Cable and ADSL technologies, broadband access in year 2000 becomes a reality for end users.

FTTH now stikes Europe and the US, but Europe seems to be more active. A lot of projects have raised in 2006 – 2007 in the northern Europe (Danemark, Sweden...) and France, with 3 different major ISPs starting their FTTH roll out in several big cities.
In the US, Verizon is the leader, celebrating the 1.000.000th FiOS customer in August 07, but Cable operators resist by providing more and more bandwith to their customers.
In France, the broadband-over-cable market seems to have a revival, offering up to 100 Mb/s data rate, to compete with forthcoming FTTH offers.

Links:
- OCDE broadband stratistics :
  http://www.oecd.org/document/7/0,3343,en_2649_34223_38446855_1_1_1_1,00.html

4.2 Broadband Market Drivers

The first key point in the broadband market drivers, is the network infrastructure. Telco / ISPs needs to invest in their network infrastructure to enable broadband for their end customers. Huge upgrades may be necessary on the core / backbone network for example, in order to support heavy load of aggregation links connecting the Point Of Presence (PoP), no matter what the access technology is (DSL, BPL, FTTH)

Once the network infrastructure is ready to handle such broadband traffic, the applications will drive the architecture:

- Application convergence : web2.0, unified messaging, web client-oriented applications, ..
- Service convergence : Broadband access, Video (IPTV, VoD), VoIP
- Network convergence : Mobile / PSTN / broadband / FTTH ...

Broadband access has revealed a new drivers, combined in the “Triple Play” offers :

- High speed Internet creates new capabilities, putting the end-user in the center of the content : end-user make the content. This move have been seen with the emerging “Web2.0” applications : videos, photos, flash animations have never easier to upload and release on video streaming website (youtube, dailymotion) social networking web sites (myspace, facebook), blogs, etc...
  This leads to have high upload data rate. Upload capability is one of the driver that broadband market can bring. This also will ease remote services such as content back-up, virtual hard drives, ...

- VoIP : certainly one of the most valuable service that data networks bring to end-user : flat rates calls worldwide, even free calls in more than 30 countries including US, Asia, Europe. VoIP enables caller ID mobility, allowing your phone number to be available wherever you are. Unified messaging system is provided as well. (Voice mails are available on a dedicated web interface)

- IPTV and VoD : broadband access now allows TV channels to be broadcasted over data network, supporting both Simple Definition anf High Definition standard. Multiple set-top-box is proposed as an option, giving the possibility to watch different content on different TV set in the same housing.
  VoD is another growing service : this service gives the ability to choose the content in a large video repository, and watch the content whenever the end user want it.

Security: with broadband access, end user are always “on”, home computers can be connecting 24h a day. This is an important driver, where ISP can make money by proposing remote tools such as security scanners, outsourced Firewall engines and centralized Antivirus systems. Parental control can be managed by broadband provider as well.

4.3 Supported services. Services needed by the society

Here is a list of services that can be used with broadband access :

- ✓ email
- ✓ E-systems Access (E-banking, E-Government, Shopping)
- ✓ Multi-PC, printer, network hard drives
- ✓ Content/Firewall parental controls
- ✓ Multimedia networking (PVR, Remote tuner/speakers, ...)
- ✓ Education
- ✓ Gaming
- ✓ Gambling
- ✓ Telecommuting
- ✓ Music subscribption
- ✓ Content publishing
- ✓ Video Entertainment
- ✓ Telephony
- ✓ Security (surveillance, access, monitoring)
- ✓ Home automation, monitoring & control
- ✓ Remore access
- ✓ Telemety Monitoring & Services
- ✓ Remote backup, remote hard drives

4.4 Penetration the world market

4.4.1 Central and South America

As opportunity can be presented the possibility of PLC technology been used without the necessity of great investments in infrastructure supplying broadband Internet. One important factor is that the electric network has coverage of 95% of the Brazilians houses. The Brazilians government project named “Luz para todos” has a goal of reach 99% of Brazilians

houses having electricity. Another factor that contributes for the interest in the technology is the great growth in the demand for broadband services that only in Brazil presented a growth of about 40% in 2006, totalizing 1.6 million of new connections.
For electric energy distribution companies it means the easiness implantation of an AMR system and the possibility to add new services in their portfolio generating new business.

4.4.2 Eastern Europe

The possibilities of the distribution of the PLC technology in Eastern Europe may be considered favorable in some regions. In the eastern countries there is not at the moment, a real thirst for broadband services or fast connections to the internet (although the television over IP protocol services are very distributed).
Many countries of the eastern area need instead to invest in telecommunications to reach (or at least come close to) the level of the western countries. The expansion of the European Union to the eastern countries will increase this need to draw nearer to the capability of western Europe. Probably because of the ex-communist nature of many eastern countries, local governments are dedicating high attention to supplying infrastructure to rural areas.. In this light, the use of the PLC technology can be of great interest, especially considering the low availability of funds of the local administrations and above all the low prices that Eastern European citizens are used to pay. While urban areas in Eastern Europe have a well developed telecommunications infrastructure, financed in part by the EU and other public funds, the rural areas have not been addressed adequately. A main obstacle to PLC application may the antiquated condition of the electric grid. Important economic efforts need be done to modernize the electric distribution grid (or to reconstruct them in the areas devastated by the war

4.4.3 Africa

[A41] PowerLine Communications or PLC technology holds high potentials for the development of African telecommunication and broadband markets. Utilizing the infrastructure of our energy networks PLC can contribute to the development of Information and Communication Technology availability and adoption in several ways.

- Firstly, PLC may reach areas without other fixed line infrastructure and provide telephone and internet access to remote areas. In this context it is very likely to be used together with other alternative platforms such as fixed wireless or satellite broadband (very diffused).

- Secondly, PLC may help to provide alternative operators with a more independent means of connecting end-users by offering an alternative to the incumbent's copper network. In this context this will aid our continent to develop infrastructure competition which increases innovation, lowers prices and leads to higher levels of penetration.

- Thirdly, PLC may assist operators to distribute last mile connectivity through fixed wireless or fiber within high-rise buildings. In this context operators may use parts of the existing electrical wiring instead of deploying new and costly structured cabling.

- In addition PLC supports our energy utilities by allowing them to more efficiently manage and operate energy distribution. Accordingly this will contribute to creating an economically viable business case for PLC operation.

PLC hence presents a concrete opportunity for Africa both regarding broadband market dynamics as well as economic and citizen driven politics. Although Africa has not yet introduced projects of sizes comparable to leading international installations started in the first years of this decade, this can actually be our benefit. This is because we can actually draw on technical advances and commence activities based on third generation technology with much higher performance and far better cost structure.

4.4.4 Asia

Until about 2006, PLC in Asia was mainly used for industrial control applications such as AMR and several trials for construction of communication infrastructure in the local loop in some developing countries. As the home network market grows and the need for indoor multi networking becomes greater (triple play, smart grid applications) PLC need be considered as a new alternative in home networking.

There is today a significant amount of PLC – associated research activity in Asia's largest countries; in China, Japan, Korea and India. The smaller countries like Malaysia, Indonesia and Singapore are following the lead of the former.

The PLC development in Asia can probably best be summed up by the following statement made by Dr. Gi-Won Lee , CEO Xeline, on October 26, 2006:
"It is imperative to have indoor communication network for services such as IP TV and Home network, and ISPs recently shows interest on PLC technology." He continues to say that "PLC triumphs over the wireless solution in areas such as speed and reliability and price of PLC products will go down dramatically as demand grows larger."

The AMR market, providing a bridge for both utility applications and in-house services is expected to grow significantly. Techno Research Group in Japan estimates a PLC potential for the home market of 132 million units for the year 2010 (global base). The major customer PLC equipment. The PLC access market has not been entirely abandoned, but as it stands at the time of this report writing, will be characterized by niche implementations.

5 BROADBAND TECHNOLOGIES

5.1 FIXED LINE TECHNOLOGIES

5.1.1 Hybrid Fiber Coax: Cable TV & Cable Modems

Note : some of the following content is an extract of the Wikipedia documentation. The original material can be found here: http://en.wikipedia.org/wiki/Hybrid_Fibre_Coaxial

Hybrid fibre-coaxial (HFC) is a broadband technology which combines optical fiber and coaxial cable. It has been commonly employed by US, Canadian, Europe and Asia cable operators since the 1990s.

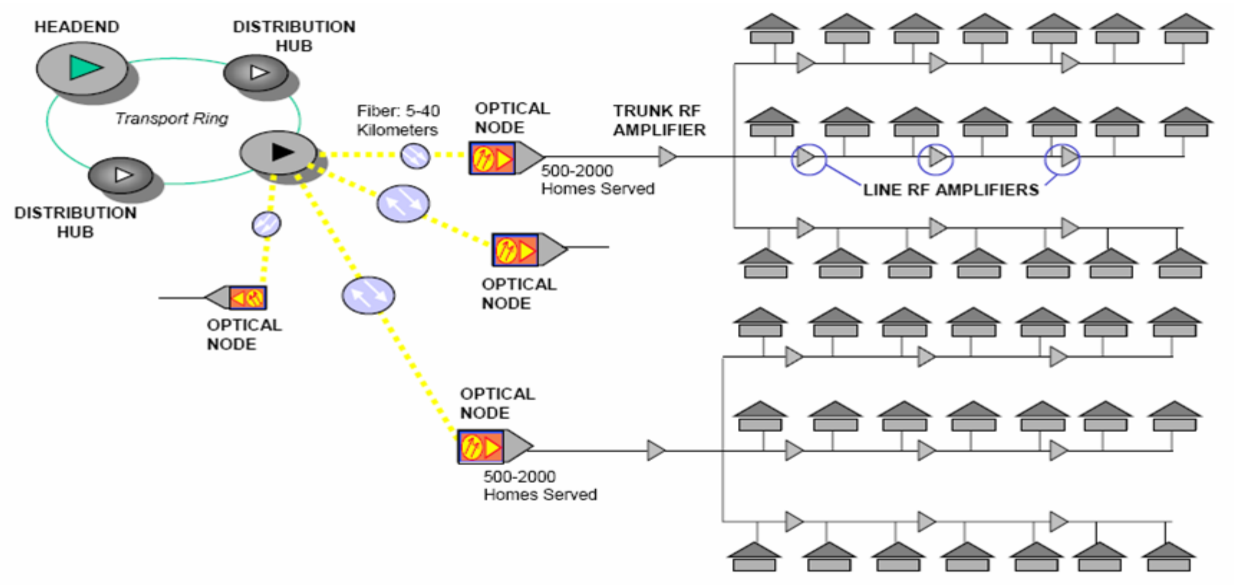


Figure 1. Hybrid Fiber Coax

Typical design of a HFC network.

The fiber optic network extends from the cable operators' master headend, sometimes to regional headends, and out to a neighbourhood's hubsite, and finally to a fiber optic node which serves anywhere from 25 to 2000 homes. A master headend will usually have satellite dishes for reception of distant video signals as well as IP aggregation routers. Some master headends also house telephony equipment for providing telecommunications services to the community. The various services are encoded, modulated and upconverted onto RF carriers, combined onto a single electrical signal and inserted into a broadband optical transmitter. This optical transmitter converts the electrical signal to a downstream optically modulated signal that is sent to the nodes. Fiber optic cables connect the header or hub to optical nodes in a point-to-point or star topology, or in some cases, in a protected ring topology.

A fiber optic node has a broadband optical receiver which converts the downstream optically modulated signal coming from the headend/hub to an electrical signal going to the homes. The fiber optic node also contains a reverse/return path transmitter that sends communication from the home back to the headend.

The optical portion of the network provides a large amount of flexibility. If there are not many fiber optic cables to the node, Wavelength division multiplexing can be utilized to combine multiple optical signals onto the same fiber. Optical filters are used to combine and split optical wavelengths onto the single fiber.

The coaxial portion of the network connects 25 to 2000 homes (500 is typical) in a tree-and-branch configuration. Radio frequency amplifiers are used at intervals to overcome cable attenuation and passive losses caused by splitting or "tapping" the cable. Trunk coaxial cables are connected to the optical node and form a coaxial backbone to which smaller distribution cables connect. The power is added to the cable line so that trunk and distribution amplifiers do not need an individual, external power source. From the trunk cables, smaller distribution cables are connected to a port of the trunk amplifier to carry the RF signal and the AC power down individual streets. If needed, line extenders, which are smaller distribution amplifiers, boost the signals to keep the power of the television signal at a level that the TV can accept. The distribution line is then "tapped" into and used to connect the individual drops to customer homes. These taps pass the RF signal and block the AC power unless there are telephony devices that need the back-up power reliability provided by the coax power system. The tap terminates into a small coaxial drop using a standard screw type connector known as an “F” connector. The drop is then connected to the house where a ground block protects the system from stray voltages. Depending on the design of the network, the signal can then be passed through a splitter to multiple TVs. If too many TVs are connected, then the picture quality of all the TVs in the house will go down.

By using frequency division multiplexing, an HFC network may carry a variety of services, including analog TV, digital TV (standard definition and HDTV), Video on demand, telephony, and high-speed data. Services on these systems are carried on Radio Frequency (RF) signals in the 5Mhz to 1000MHz frequency band.

The HFC network is bi-directional, meaning that signals are carried in both directions on the same network from the headend/hub office to the home, and from the home to the headend/hub office. The *forward-path* or *downstream* signals carry information from the headend/hub office to the home, such as video content, voice and internet data. The *return-path* or *upstream* signals carry information from the home to the headend/hub office, such as control signals to order a movie or internet data to send an email. The *forward-path* and the *return-path* are actually carried over the same coaxial cable in both directions on the same network from the headend/hub office to the home, and from the home to the headend/hub office. The *forward-path* or *downstream* signals carry information from the headend/hub office to the home, such as video content, voice, and IP packets coming from the Internet. The *return-path* or *upstream* signals carry information from the home to the headend/hub office such as set top box control signals, IP packets going to the Internet, and voice. In order to prevent interference of signals, the frequency band is divided into two sections. In countries that have traditionally used NTSC, the sections are 52 MHz to 1000 MHz for *forward-path* signals, and 5 MHz to 42 MHz for *return-path* signals. Other countries use different band sizes, but are similar in that there is much more bandwidth for downstream communication instead of upstream communication.

Multiple System operators (MSOs) developed methods of sending the various services over RF signals on the fiber optic and coaxial cables. The original method to transport video over the HFC network and, still the most widely used method, is by modulation of standard analog TV channels which is similar to the method used for transmission of over-the-air broadcast television channels. One analog TV channel occupies a 6 MHz-wide frequency band in NTSC-based systems, or an 8 MHz-wide frequency band in PAL or SECAM-based systems. Each channel is centered on a specific frequency carrier so that there is no interference with adjacent or harmonic channels. Digital TV channels offer a more-efficient way to transport video by using MPEG-2 or MPEG-4 coding over Quadrature amplitude modulation (QAM) channels. To be able to view a digitally modulated channel, home, or customer-premises equipment (CPE), e.g. digital televisions, computers, or set-top boxes, are required to convert the RF signals to signals that are compatible with display devices such as analog televisions or computer monitors. The Federal Communication Commission (FCC) has ruled that consumers can obtain a cable card from their local MSO to authorize viewing digital channels. By using digital compression techniques, multiple standard and high-definition TV channels can be carried on one 6 or 8 MHz frequency carrier thus increasing the channel carrying-capacity of the HFC network by 10 times or more versus an all analog network. Note that a digital tuner (i.e. TV set-top box) is not required for standard analog TV channels since most televisions have integrated analog tuners that can decode the signal, unless some type of scrambling is used.

Today, IP services over CableTV networks provide different level of data rate, depending of the country market. Some examples :

- In the US, end users get an average of 3-to-4 Mb/s on their cable connection.
- In Canada, some providers deliver up to 10 Mb/s connections
- In UK, providers offer from 1 Mb/s up to 8 Mb/s (from http://www.cable.co.uk)
- In France, due to high competing market, cable operators launched 100 Mb/s offers, after delivering 30 Mb/s over the cable.
- In Switzerland, the cable compete with DSL lines and offers up to 6 Mb/s

Summary of characteristics:

Technology	HFC
Simplicity of deployment	Easy if already exists a cable TV network. Expensive if it is necessary to deploy the network

Spectrum Usage	5-1000 Mhz, 6-8 Mhz/channel
Capacity Shared?	Yes
Symmetry	Asymmetric.
Capacity	USA: 3 - 4 Mbps Canada: up to 10 Mbps UK: 1 - 8 Mbps France: up to 100 Mbps Switzerland: up to 6 Mbps
Max Range	Up to 100 km using amplifiers
Strengths	Uses existing cable TV networks
Weaknesses	Limited bandwidth and asymmetric

Table 3. Summary HFC

5.1.2 Digital Subscriber Line (xDSL)

Note : some of the following content is an extract of the Wikipedia documentation. The original material can be found here : <u>http://en.wikipedia.org/wiki/Dsl</u>

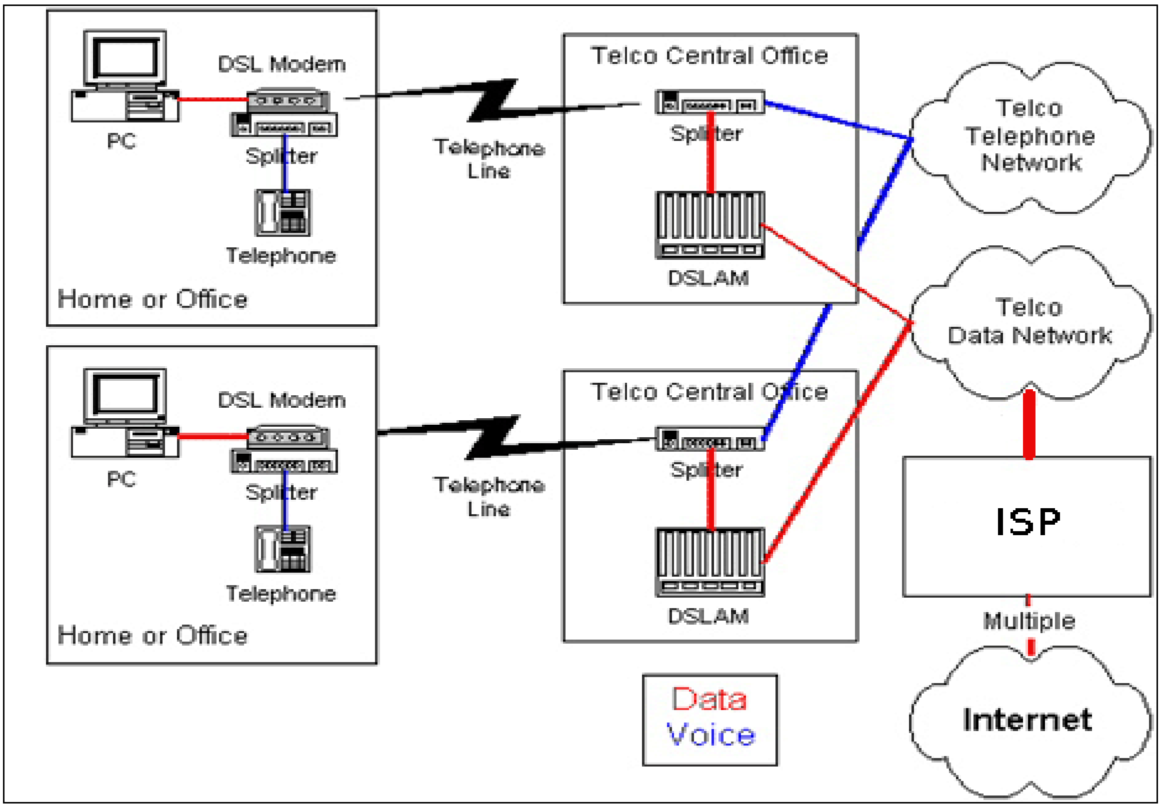


Figure 2. xDSL

Typical DSL network design

DSL or xDSL, is a family of technologies that provide digital data transmission over the wires of a local telephone network. DSL originally stood for digital subscriber loop, although in recent years, many have adopted digital subscriber line as a more marketing-friendly term for the most popular version of consumer-ready DSL, ADSL.

Typically, the download speed of consumer DSL services ranges from 256 kilobits per second (kbit/s) to 24,000 kbit/s, depending on DSL technology, line conditions and service level implemented. Typically, upload speed is lower than download speed for Asymmetric Digital Subscriber Line (ADSL) and equal to download speed for Symmetric Digital Subscriber Line (SDSL).

Some variants of DSL connections, like ADSL and very high speed DSL (VDSL), typically work by dividing the frequencies used in a single phone line into two primary 'bands'. The ISP data is carried over the high frequency band (25 kHz and above) whereas the voice is carried over the lower frequency band (4 kHz and below). The user typically installs a DSL filter on each phone. This filters out the high frequencies from the phone, so that the phone only sends or receives the lower frequencies (the human voice), creating two independent 'bands'. Thus the DSL modem and the phone can simultaneously use the same phone line without interfering with each other.

Digital subscriber line technology was originally implemented as part of the ISDN specification, which is later reused as IDSL. Higher speed DSL connections like HDSL and SDSL are developed to extend the range of DS1 services on copper lines. Consumer oriented ADSL is designed to operate also on a BRI ISDN line, which itself is a form of DSL, as well as on an analog phone line.

Joe Lechleider at Bellcore (now Telcordia Technologies) developed ADSL in 1988 by placing wideband digital signals above the existing baseband analog voice signal carried between telephone company central offices and customers on conventional twisted pair cabling.

Older ADSL standards can deliver 8 Mbit/s to the customer over about 2 km (1.25 miles) of unshielded twisted pair copper wire. The latest standard, ADSL2+, can deliver up to 24 Mbit/s, depending on the distance from the DSLAM. Distances greater than 2 km (1.25 miles) significantly reduce the bandwidth usable on the wires, thus reducing the data rate.

The local loop of the Public Switched Telephone Network was initially designed to carry POTS voice communication and signaling, since the concept of data communications as we know it today did not exist. For reasons of economy, the phone system nominally passes audio between 300 and 3,400 Hz, which is regarded as the range required for human speech to be clearly intelligible. This is known as voiceband or commercial bandwidth.

At the local telephone exchange (UK terminology) or central office (US terminology) the speech is generally digitized into a 64 kbit/s data stream in the form of an 8 bit signal using a sampling rate of 8,000 Hz, therefore – according to the Nyquist theorem – any signal above

4,000 Hz is not passed by the phone network (and has to be blocked by a filter to prevent aliasing effects).

The local loop connecting the telephone exchange to most subscribers is capable of carrying frequencies well beyond the 3.4 kHz upper limit of POTS. Depending on the length and quality of the loop, the upper limit can be tens of megahertz. DSL takes advantage of this unused bandwidth of the local loop by creating 4312.5 Hz wide channels starting between 10 and 100 kHz, depending on how the system is configured. Allocation of channels continues at higher and higher frequencies (up to 1.1 MHz for ADSL) until new channels are deemed unusable. Each channel is evaluated for usability in much the same way an analog modem would on a POTS connection. More usable channels equates to more available bandwidth, which is why distance and line quality are a factor (the higher frequencies used by DSL travel only short distances). The pool of usable channels is then split into two different frequency bands for upstream and downstream traffic, based on a preconfigured ratio. This segregation reduces interference. Once the channel groups have been established, the individual channels are bonded into a pair of virtual circuits, one in each direction. Like analog modems, DSL transceivers constantly monitor the quality of each channel and will add or remove them from service depending on whether they are usable.

One of the greatest contributions to DSL was his insight that an asymmetric arrangement offered more than double the bandwidth capacity of synchronous DSL. This allowed Internet Service Providers to offer efficient service to consumers, who taken profit greatly from the ability to download large amounts of data but rarely needed to upload comparable amounts. ADSL supports two modes of transport: fast channel and interleaved channel. Fast channel is preferred for streaming multimedia, where an occasional dropped bit is acceptable, but lags are less so. Interleaved channel works better for file transfers, where transmission errors are impermissible, even though resending packets may increase latency.

he first step is the physical connection. On the customer side, the DSL modem is hooked up to a phone line. The telephone company (telco) connects the other end of the line to a DSLAM, which concentrates a large number of individual DSL connections into a single box. The location of the DSLAM depends on the telco, but it cannot be located too far from the user because of attenuation, the loss of data due to the large amount of electrical resistance encountered as the data moves between the DSLAM and the user's DSL modem. It is common for a few residential blocks to be connected to one DSLAM. When the DSL modem is powered up, it goes through a sync procedure. The actual process varies from modem to modem but can be generally described as:

1. The modem does a self-test.

2. The modem checks the connection between the modem and the computer. For residential variations of DSL, this is usually the Ethernet port or a USB port; in rare models, a FireWire port is used. Older DSL modems sported a native ATM interface (usually, a 25 MBit serial interface). Also, some variations of DSL (such as SDSL) use synchronous serial connections.

3. The modem then attempts to synchronize with the DSLAM. Data can only come into the computer when the DSLAM and the modem are synchronized. The synchronization process is relatively quick (in the range of seconds) but is very complex, involving extensive tests that allow both sides of the connection to optimize the performance according to the characteristics of the line in use. External, or stand-alone modem units have an indicator labeled "CD", "DSL", or "LINK", which can be used to tell if the modem is synchronized. During synchronization the light flashes; when synchronized, the light stays lit, usually with a green colour.

Modern DSL gateways have more functionality and usually go through an initialization procedure that is very similar to a PC starting up. The system image is loaded from the flash memory; the system boots, synchronizes the DSL connection and establishes the IP connection between the local network and the service provider, using protocols such as DHCP or PPPoE. The system image can usually be updated to correct bugs, or to add new functionality.

Summary of characteristics:

Technology	ADSL	VDSL	ADSL2+
Simplicity of deployment	Easy where it can be used the existing POTs	Easy where it can be used the existing POTs	Easy where it can be used the existing POTs
Spectrum Usage	Up to 1.1 MHz	Up to 1.1 MHz	Up to 2.2 MHz
Capacity Shared?	No	No	No
Symmetry	Asymmetric.	Asymmetric	Asymmetric
Capacity	From 1,5 Mbps (5.4 km) to 12 Mpbs (300 m)	From 13 Mbps (1.3 km) to 52 Mpbs (300 m)	From 7.5 Mbps (2.7 km) to 26 Mpbs (300 m)
Max Range	Up to 5.4 km	Up to 1.3 km	Up to 2.7 km
Strengths	Uses existing POTs	Mainly uses existing POTs	Uses existing POTs
Weaknesses	Distance sensitive, asymmetric and distance sensitive	Bandwidth is very distance sensitive. Requires fibre feeds	Bandwidth is distance sensitive

Table 4. Summary xDSL

5.1.3 Fiber to the Home/Curb (FTTH/FTTC)

*Note : some of the following content is an extract of the Wikipedia documentation. The original material can be found here :**http://en.wikipedia.org/wiki/Ftth***

Fiber to the home (FTTH) is a form of fiber-optic communication delivery in which an optical fiber is run directly onto the customers' home. This contrasts with other fiber-optic communication delivery strategies such as fiber to the node (FTTN), fiber to the curb (FTTC), or hybrid fibre-coaxial (HFC), all of which depend upon more traditional methods such as copper wires or coaxial cable for "last mile" delivery.

Here is a view of the different “FTTx” designs:

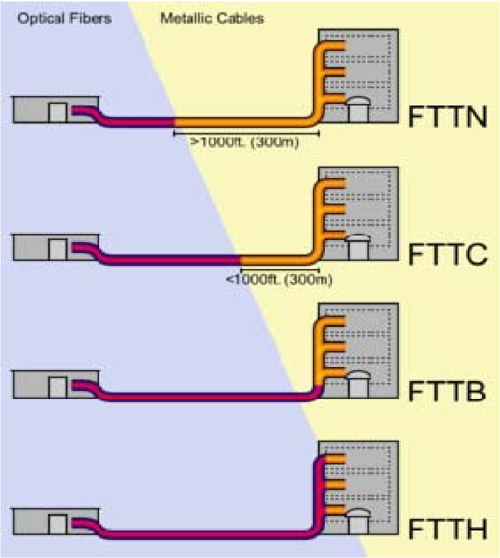


Figure 3. Fiber To The “X” designs

Optical portion

Optical distribution networks have several competing technologies.

Direct fiber :

The simplest optical distribution network can be called direct fiber. In this architecture, each fiber leaving the central office goes to exactly one customer (Point to Point fiber or P2P). Such networks can provide excellent bandwidth since each customer gets their own dedicated fiber extending all the way to the central office. However, this approach is extremely costly due to the amount of fiber and central office machinery required. It is usually used only in instances where the service area is very small and close to the central office.

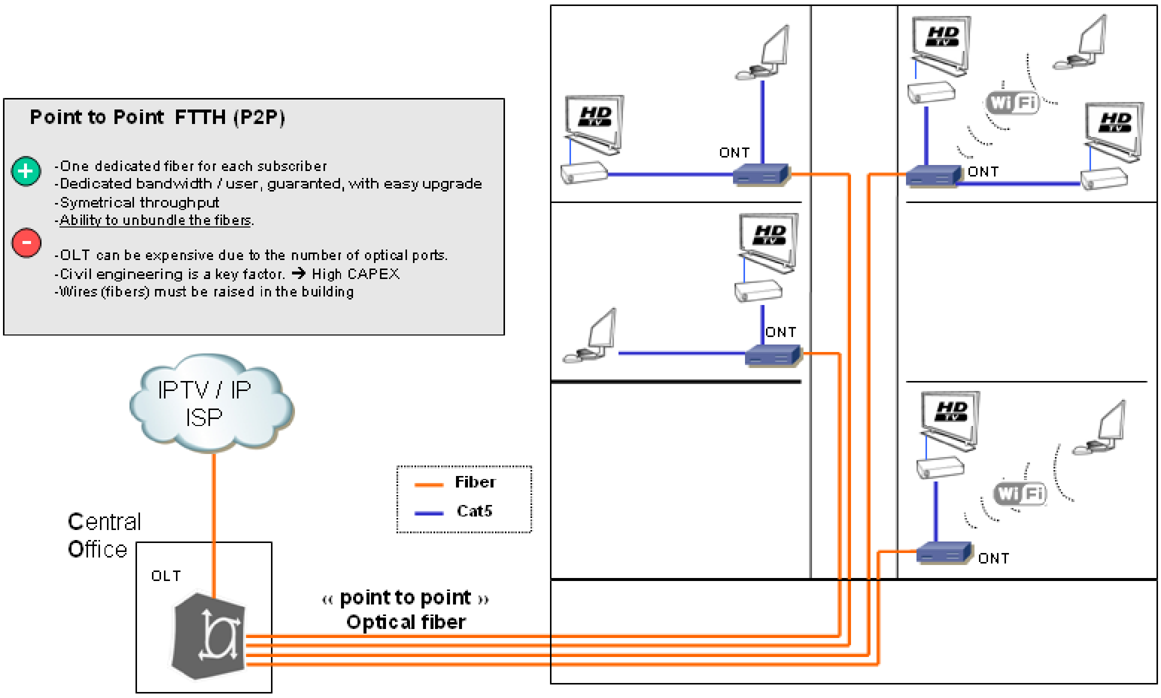


Figure 4. General overview of a P2P FTTH network with pros & cons.

Shared fiber

More commonly each fiber leaving the central office is actually shared by many customers. It is not until such a fiber gets relatively close to the customers that it is split into individual customer-specific fibers. There are two competing optical distribution network architectures which achieve this split: active optical networks (AONs) and passive optical networks (PONs).

Active optical network

Comparison showing how a typical active optical network handles downstream traffic differently than a typical passive optical network. The type of active optical network shown is a star network capable of multicasting. The type of passive optical network shown is a star network having multiple splitters housed in the same cabinet.

Comparison showing how a typical active optical network handles downstream traffic differently than a typical passive optical network. The type of active optical network shown is a star network capable of multicasting. The type of passive optical network shown is a star network having multiple splitters housed in the same cabinet.

Active optical networks rely on some sort of electrically powered equipment to distribute the signal, such as a switch, router, or multiplexer. Each signal leaving the central office is directed only to the customer for which it is intended. Incoming signals from the customers avoid colliding at the intersection because the powered equipment there provides buffering.

As of 2007, the most common type of active optical networks are called active ethernet, a type of ethernet in the first mile (EFM). Active ethernet uses optical ethernet switches to distribute the signal, thus incorporating the customers' premises and the central office into one giant switched ethernet network. Such networks are identical to the ethernet computer networks used in businesses and academic institutions, except that their purpose is to connect homes and buildings to a central office rather than to connect computers and printers within a campus. Each switching cabinet can handle up to 1,000 customers, although 400-500 is more typical. This neighbourhood equipment performs layer 2/layer 3 switching and routing, offloading full layer 3 routing to the carrier's central office. The IEEE 802.3ah standard enables service providers to deliver up to 100 Mbit/s full-duplex over one single-mode optical fiber to the premises depending on the provider.

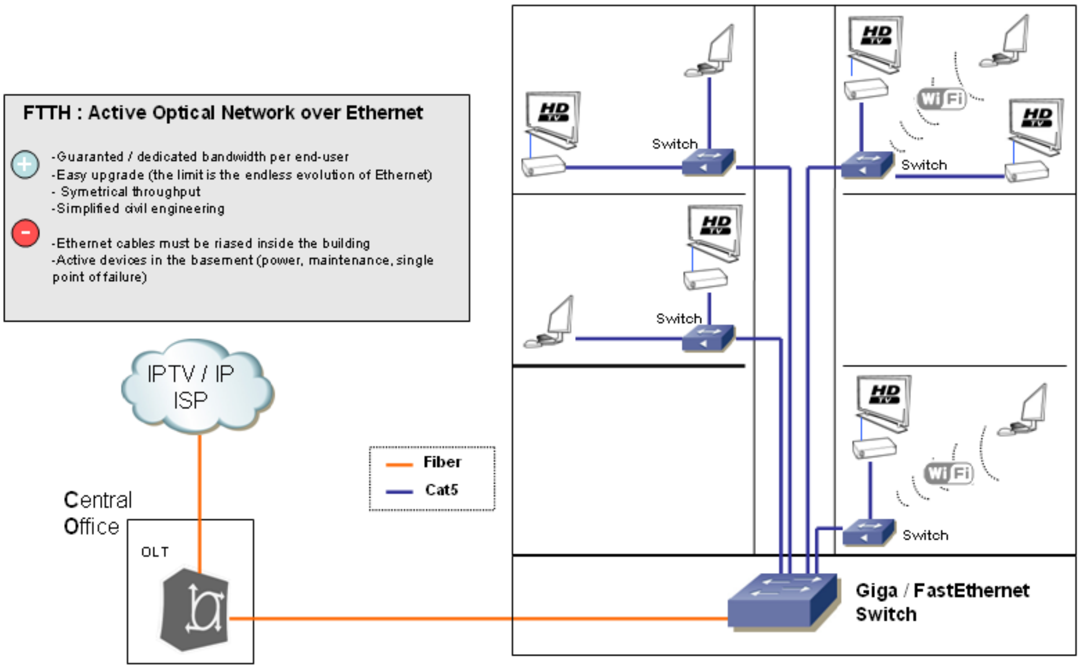


Figure 5. General overview of an AoN FTTH network using Ethernet with pros & cons.

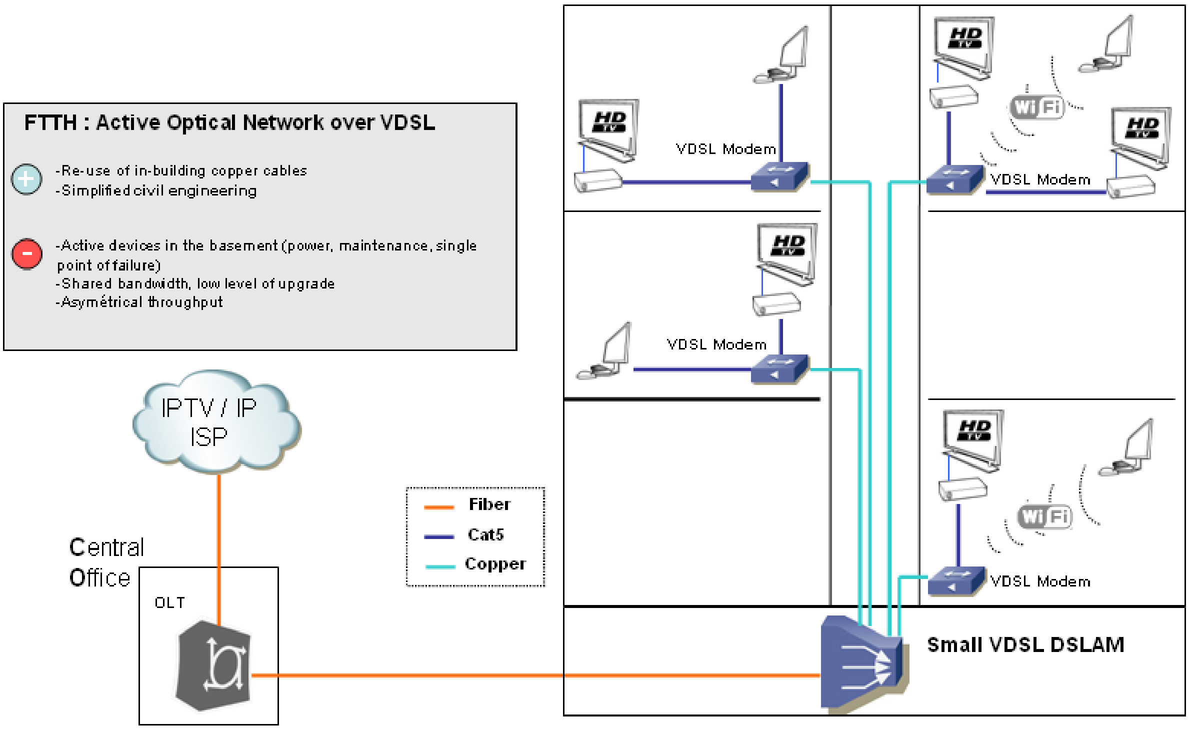


Figure 6.General overview of a AoN FTTH network using VDSL with pros & cons.

Passive optical network

It has been suggested that this article or section be merged into Passive_optical_network.

Passive optical networks do not use electrically powered components to split the signal. Instead, the signal is distributed using beam splitters. Each splitter typically splits a fiber into 16, 32, or 64 fibers, depending on the manufacturer, and several splitters can be aggregated in a single cabinet. A beam splitter cannot provide any switching or buffering capabilities; the resulting connection is called a point-to-multipoint link. For such a connection, the optical network terminals on the customer's end must perform some special functions which would not otherwise be required. For example, due to the absence of switching capabilities, each signal leaving the central office must be broadcast to all users served by that splitter (including to those for whom the signal is not intended). It is therefore up to the optical network terminal to filter out any signals intended for other customers. In addition, since beam splitters cannot perform buffering, each individual optical network terminal must be coordinated in a multiplexing scheme to prevent signals leaving the customer from colliding at the intersection. Two types of multiplexing are possible for achieving this: wavelength-division multiplexing and time-division multiplexing. With wavelength-division multiplexing, each customer transmits their signal using a unique wavelength. With time-division multiplexing, the customers "take turns" transmitting information. As of early 2007, only time-division multiplexing was technologically practical.

In comparison with active optical networks, passive optical networks have significant advantages and disadvantages. They avoid the complexities involved in keeping electronic equipment operating outdoors. They also allow for analog broadcasts, which can simplify the delivery of analog television. However, because each signal must be pushed out to everyone served by the splitter (rather than to just a single switching device), the central office must be equipped with a particularly powerful piece of transmitting equipment called an optical line terminal (OLT). In addition, because each customer's optical network terminal must transmit all the way to the central office (rather than to just the nearest switching device), customers can't be as far from the central office as is possible with active optical networks.

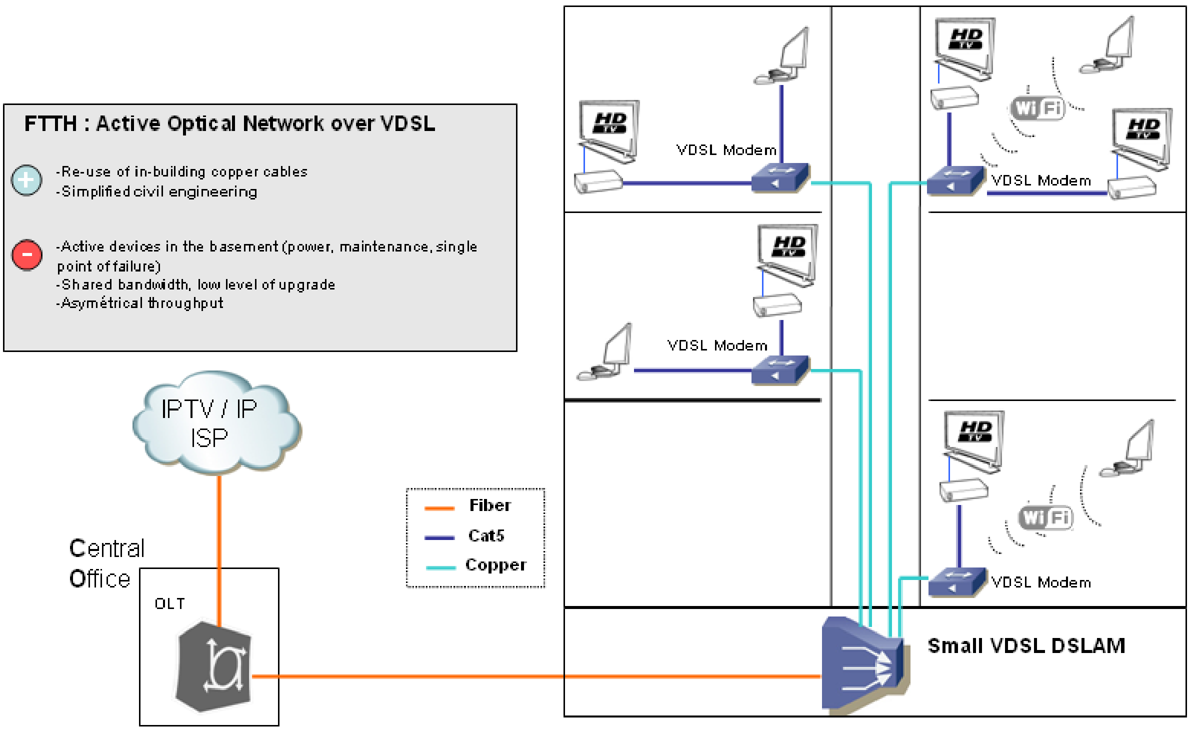


Figure 7. General overview of a PN FTTH network with pros & cons.

Fiber to the curb (FTTC), also called fibre to the kerb (FTTK), is a telecommunications system based on fiber-optic cables run to a platform that serves several customers. Each of these customers has a connection to this platform via coaxial cable or twisted pair.

Fiber to the curb allows delivery of broadband services such as high speed internet. High speed communications protocols such as broadband cable access (typically DOCSIS) or some form of DSL are used between the cabinet and the customers. The data rates vary according to the exact protocol used and according to how close the customer is to the cabinet.

FTTC is subtly distinct from FTTN or FTTP (all are versions of Fiber in the Loop). The chief difference is the placement of the cabinet. FTTC will be placed near the "curb" which differs from FTTN which is placed far from the customer and FTTP which is placed right at the serving location.

Unlike the competing fiber to the premises (FTTP) technology, fiber to the curb can use the existing coaxial or twisted pair infrastructure to provide last mile service. For this reason, fiber to the curb costs less to deploy. However, it also has lower bandwidth potential than fiber to the premises.

Summary of characteristics:

Technology	FTTH
Simplicity of deployment	Difficult. Requires new fibre access network overlay
Spectrum Usage	T Hz
Capacity Shared?	PON: Yes P2P: No
Symmetry	Symmetric
Capacity	Up to 1 Gbps per channel per fibre
Max Range	20 km
Strengths	Very high bandwith
Weaknesses	Expensive deployment of the network

Table 5. Summary FTTH

5.1.4 Powerline Communications (PLC)

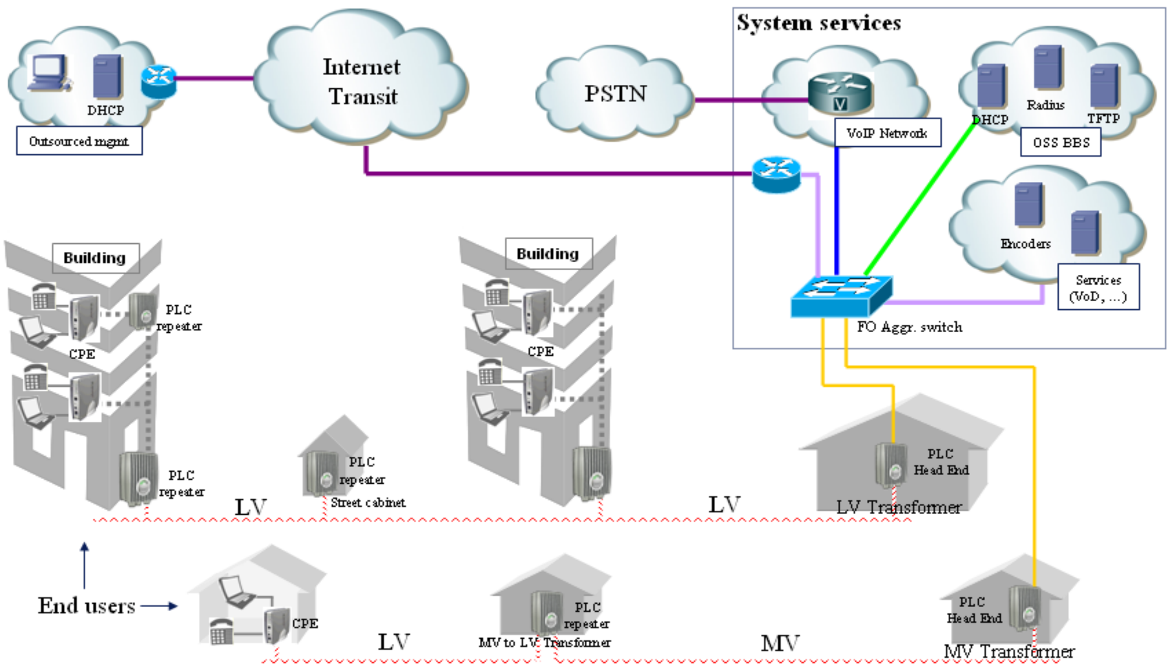


Figure 8. Overview of a PLC network, using both MV and LV

Broadband over power lines (BPL), also known as power-line internet or Powerband, is the use of PLC technology to provide broadband Internet access through ordinary power lines. A computer (or any other device) would need only to plug a BPL "modem" into any outlet in an equipped building to have high-speed Internet access.

PLC modems transmit in medium and high frequency (1.6 to 80 MHz electric carrier). The asymmetric speed in the modem is generally from 256 kbit/s to 2.7 Mbit/s. In the repeater situated in the meter room the speed is up to 45 Mbit/s and can be connected to 256 PLC modems. In the medium voltage stations, the speed from the head ends to the Internet is up to 135 Mbit/s. To connect to the Internet, utilities can use optical fiber backbone or wireless link.

The system has a number of complex issues, the primary one being that power lines are inherently a very noisy environment. Every time a device turns on or off, it introduces a pop or click into the line. Energy-saving devices often introduce noisy harmonics into the line. The system must be designed to deal with these natural signaling disruptions and work around them.

Broadband over powerlines has developed faster in Europe than in the United States due to a historical difference in power system design philosophies. Nearly all large power grids transmit power at high voltages in order to reduce transmission losses, then near the customer use step-down transformers to reduce the voltage. Since BPL signals cannot readily pass through transformers — their high inductance makes them act as low-pass filters, blocking high-frequency signals — repeaters must be attached to the transformers. In the U.S., it is common for a small transformer hung from a utility pole to service a single house or a small number of houses. In Europe, it is more common for a somewhat larger transformer to service 10 or 100 houses. For delivering power to customers, this difference in design makes little difference with power distribution, but it means delivering BPL over the power grid of a typical U.S. city will require an order of magnitude more repeaters than would be required in a comparable European city. However, since bandwidth to the transformer is limited, this can increase the speed at which each household can connect, due to fewer people sharing the same line. One possible alternative is to use BPL as the backhaul for wireless communications, by for instance hanging Wi-Fi access points or cellphone base stations on utility poles, thus allowing end-users within a certain range to connect with equipment they already have. In the near future, BPL might also be used as a backhaul for WiMAX networks.

Modern BPL systems use OFDM modulation which allows the mitigation of interference with radio services by removing specific frequencies used.

Much higher speed transmissions using microwave frequencies transmitted via a newly discovered surface wave propagation mechanism called E-Line have been demonstrated using only a single power line conductor. These systems have shown the potential for symmetric and full duplex communication well in excess of 1 Gbit/s in each direction. Multiple WiFi channels with simultaneous analog television in the 2.4 and 5.3 GHz

unlicensed bands have been demonstrated operating over a single medium voltage line. Furthermore, because it can operate anywhere in the 100 MHz - 10 GHz region, this technology can completely avoid the interference issues associated with utilizing shared spectrum while offering the greater flexibility for modulation and protocols found for any other type of microwave system.

Technology

Technology is available from designs based on a number of different non compatible silicon vendors. These include Intellon's INT6000 silicon which meets the HomePlug AV specification (not interoperable with HomePlug 1.0 or Intellon's proprietary 85 Mbit/s Turbo mode) or DS2 DSS9XXX series silicon which complies with Universal Powerline Association standards; and other solutions from Panasonic and SiConnect. Some solutions are based on OFDM modulation with 1536 carriers and TDD or FDD channel access method. DS2 silicon may operate between 1 and 34 MHz. It provides a high dynamic range (90 dB) and offers frequency division and time division repeating capabilities. These characteristics allow the implementation of quality of service (QoS) and class of service (CoS) capabilities. Technologies deliver speeds of up to 200 Mbit/s at the physical layer and 130 Mbit/s at the application layer although actual throughput rates are degraded by the attenuation and the level of noise.

Summary of characteristics:

Technology	PLC
Simplicity of deployment	Easy. No new wiring needs.
Spectrum Usage	1-30 Mhz
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	200 Mbps shared medium 2 - 4 Mpbs per user
Max Range	Up to 3 km in Medium Voltage Up to 200 m in Low Voltage
Strengths	Uses existing power grid
Weaknesses	No standards available

Table 6. Summary PLC

5.1.4.1 Standardisation

For the last ten years standardization has been one of the best way to widely open a market to new technologies. Most of the major market successes were the fact of standardized technologies when the standard is worldwide recognized. We consider that is it important to highlight what is the status of PLC standardization process in order to know how this issue could affect to the future of this technology.

Today the PLC players are acting to have worldwide standards and expected to have two major standards released for end of 2009.

One is on going through IEEE organization:

IEEE P1901 Standard – *Protocols* - Release date expected end of 2009

The second one is on going through IEC Organization.

CISPR 257CD – *EMC (Electro Magnetic Compatibility*) - Release date expected on October 2009

OPERA is widely invested in standardization process through IEEE and IEC organizations. OPERA contribution is well recognized thanks to the high level of knowledge developed either in protocol, EMC than in field deployment expertise.

5.1.4.1.1 IEEE P1901 Standard – Protocols

IEEE organization

The IEEE (Institute of Electrical and Electronics Engineers, Inc.) is the world's largest technical professional society. Through its more than 375,000 members in 160 countries, the organization is a leading authority on a wide variety of areas ranging from aerospace systems, computers and telecommunications to biomedical engineering, electric power and consumer electronics. Dedicated to the advancement of technology, the IEEE publishes 30 percent of the world's literature in the electrical and electronics engineering and computer science fields, and has developed nearly 900 active industry standards. The organization annually sponsors more than 850 conferences worldwide.

IEEE P1901 Standard [21]:

Standard for Broadband over Power Line Networks: Medium Access Control and Physical Layer Specifications

Working Group launched date: 9 June 2005 after the approval of the Project Authorization Request (PAR) by the IEEE-SA.

Scope of IEEE P1901 Standard:

The project will develop a standard for high speed (>100 Mbps at the physical layer) communication devices via alternating current electric power lines, so called Broadband over Power Line (BPL) devices. The standard will use transmission frequencies below 100 MHz. This standard will be usable by all classes of BPL devices, including BPL devices used for the first-mile/last-mile connection (<1500 m to the premise) to broadband services as well as BPL devices used in buildings for LANs and other data distribution (<100m between devices). This standard will focus on the balanced and efficient use of the power line communications channel by all classes of BPL devices, defining detailed mechanisms for coexistence and interoperability between different BPL devices, and ensuring that desired bandwidth and quality of service may be delivered. The standard will address the necessary security questions to ensure the privacy of communications between users and allow the use of BPL for security sensitive services. This standard is limited to the physical layer and the medium access sub-layer of the data link layer, as defined by the International Organization for Standardization (ISO) Open Systems Interconnection (OSI) Basic Reference Model. The effort will begin with an architecture investigation, and this will form the basis for detailed scope of task groups that will work within P1901 to develop the components of the final standard.

In summary the scope of the IEEE P1901 Standard could be define as:

- Physical and Medium Access Control layers
- All applications: from Access to In-home
- Peaceful coexistence between applications is mandatory
- Level of interoperability to be refined by the WG
- Security

Purpose of IEEE P1901 Standard:

New modulation techniques offer the possibility to use the power lines for high speed communications. This new high speed media is open, and locally shared by several BPL devices. Without an independent, openly defined standard, BPL devices serving different applications will conflict with one another and provide unacceptable service to all parties. The standard will provide a minimum implementation subset which allows the fair coexistence of the BPL devices. The full implementation will provide the interoperability among the BPL devices, as well as interoperability with other networking protocols, such as bridging for seamless interconnection via 802.1. It is also the intent of this effort to quickly progress towards a robust standard powerline applications may begin to impact the marketplace. The standard will also comply with EMC limits set by national regulators, so as to ensure successful coexistence with wireless and telecommunications systems.

Reason for the IEEE P1901 Standard:

Coexistence of the BPL devices on the same power lines is a basic need of the BPL market.

Devices from different vendors should continue to operate properly while using the same powerlines. Interoperability will support the growth of the emerging BPL market. It will benefit the consumer market, enabling consumers to use devices from different vendors and warranting the availability of lower cost equipment. Interoperability will also benefit the access market, allowing low cost extensions of the services in the houses. It also will benefit the electric utility industry, enabling power companies to improve the efficiency and reliability of electricity distribution by creating low-cost, real-time connections across the distribution system, a capability rarely deployed today.

IEEE P1901 Working Group:

The working group, formed in June 2005, has grown from 20 to more than 60 members. Members are PLT technology providers, CE companies, access companies, utilities, service providers, chip vendors, retailers and BPL associations. The Working Group has a worldwide membership covering U.S., Europe and Asia. Each entity has one vote following the IEEE-SA Corporate Standards Program.

IEEE-SA Corporate Standards Program

The IEEE-SA Corporate Standards Program allows entities to create standards within an ANSI-accredited, open process. Standards are developed in company-based working groups in which each member has one vote. This industry-oriented program allows for standards creation in as little as one to two years, depending on participant commitment and funding for IEEE services that can optimize all phases of the standards development process.

IEEE P1901 milestones

June 2005 PAR approved

November 2005 Adoption of the general work flow (fig: 9) - Formation of a sub-group to develop unified requirements

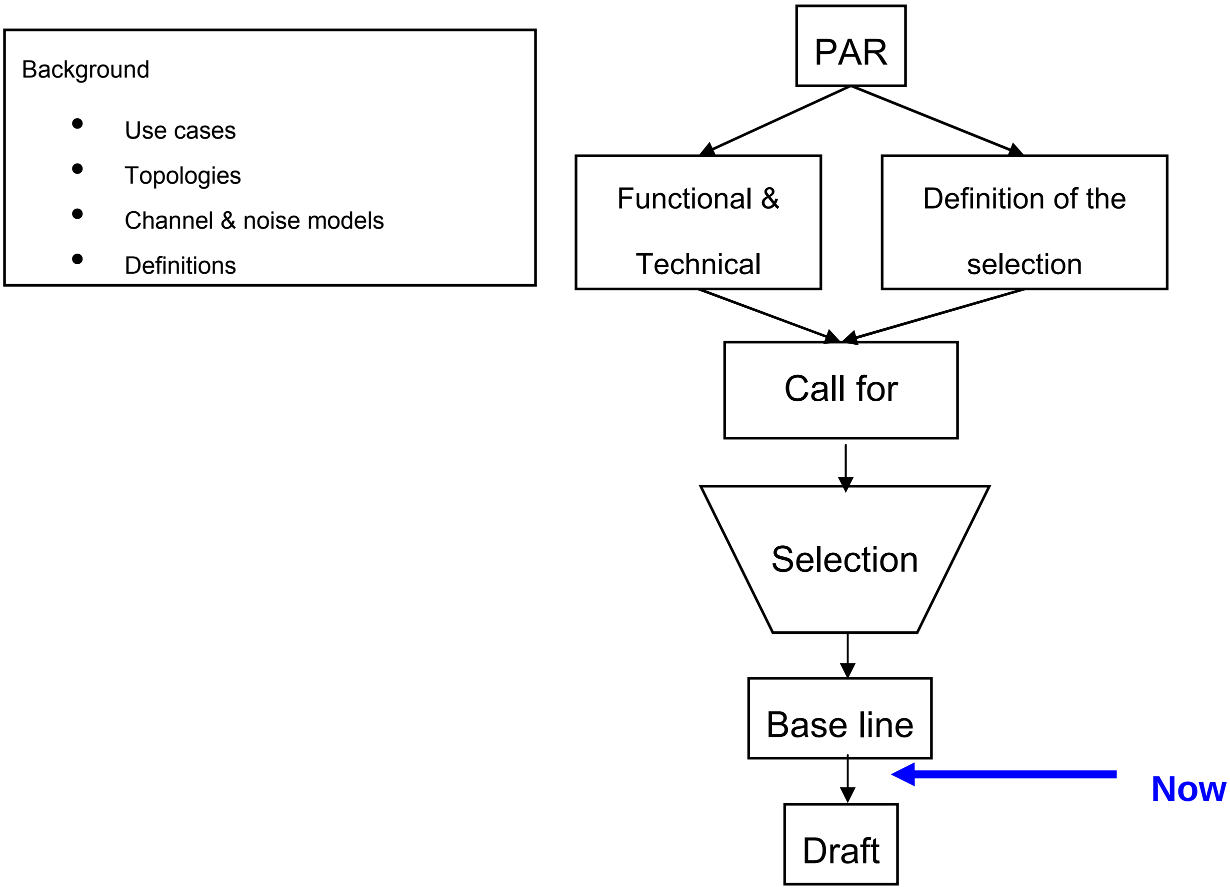


Figure 9. IEEE P1901 General work flow

January 2006 Approval of the use cases - Decision to split the requirements into three clusters: In-Home, Access and Coexistence/Interoperability

March 2006 Approval of the down selection process to achieve the baseline of the standard - Approval of the description of topologies.

September 2006 Approval of the channel and noise models.

February 2007 Approval of 400 requirements split into three clusters: access, in-home and coexistence - Calls for technical proposals

June 2007 12 proposals received; 4 proposals per cluster of requirements

July 2007 11 proposals passed the low hurdle vote; 4 in-home proposals, 4 access proposals and 3 coexistence proposals

September 2007 Only two proposals per cluster remain for consideration after voluntary mergers.

October 2007 One in-home proposal and one access proposal remain as candidates for confirmation after the first round of elimination voting.

March 2008 A single coexistence proposal remains as candidate for confirmation after the last round of elimination voting.

July 2008 The first round of confirmation voting for the in-home, access, and coexistence proposals is held. All three votes fail.

September 2008 The second round of confirmation voting for the in-home, access, and coexistence proposals is held. The votes on the in-home and access proposals fail. The vote on the coexistence proposal is ruled invalid because the number of abstain votes exceeds the established percentage.

November 2008 The second round of confirmation voting for the in-home and access proposals is held. Both votes fail.

Report on the meeting held in Kyoto, Japan, 16-19 December 2008

As an initial activity during this meeting, the Working Group discussed the comments received on the proposal that failed the previous confirmation vote in San Francisco in November.

Among the received comments, a group of companies involved in Access BPL networking, IBM, Ambient, IBEC, Corinex, UPLC, PLC Ventures, and the chip vendor DS2, submitted a proposal to add an ITU-T Study Group 15/Q4 G.hn Recommendation Compatible PHY/MAC option to the FFT PHY/MAC and the Wavelet PHY/MAC defined in the In-Home and Access proposals that are candidates for confirmation. HomePlug, Panasonic, Mitsubishi, Hisilicon and the co-authors of the surviving proposals accepted the proposed change and submitted updated In-Home and Access proposals for a second round of confirmation voting.

The proposals require 75% majority approval from the working group to become part of the baseline of the standard.

The confirmation vote on the updated Panasonic-HomePlug-HiSilicon In-Home proposal was conducted first. The proposal received affirmative votes from 85% of the working group and thus passed to become part of the baseline of the draft standard.

The confirmation vote on the updated HomePlug-Panasonic-Mitsubishi Access proposal was conducted second. The proposal received affirmative votes from 97% of the working group and thus passed to become part of the baseline of the draft standard.

The confirmation vote on the CEPCA-SiConnect-HomePlug Coexistence proposal was conducted last. The proposal received affirmative votes from 100% of the working group and thus passed to become part of the baseline of the draft standard.

With these confirmation votes, a major milestone has been reached. The next step is the development of the first version of the draft standard based on the three confirmed proposals. A Technical Sub Group was formed to perform this task.

The next meeting is scheduled for 3-6 February in Miami, FL, USA

"This is a major milestone in the development of a BPL standard," says Jean-Philippe Faure, chair of the IEEE P1901 Working Group. "The approved proposals form the baseline content for the standard. Our next steps will be to harmonize and improve the different sections and then finalize the draft standard for IEEE Sponsor Ballot by the end of year."

All the Opera contributions had been included in the voted baseline. A worldwide standard is expected before end of the year.

5.1.4.1.2 IEC Standard - CISPR 257CD

IEC (International Electrotechnical Commission)

The IEC is the world's leading organization that prepares and publishes International Standards for all electrical, electronic and related technologies — collectively known as electrotechnology.

CISPR (Comite International Special des Perturbations Radioelectriques)

The Comite International Special des Perturbations Radioelectriques or in English the International special committee on Radio Interference is best known by its abbreviation CISPR, is a special committee under the sponsorship of the International Electrotechnical Commissions (IEC). The membership is from national committees of the IEC, and other number of other international organizations interested in the reduction of the radio interference.

The main development steps of standards in CISPR are:

• DC: draft for comment

• CD: Committee Draft

• CDV: Committee Draft for Vote

• FDIS: Final Draft International Standard

When the FDIS is approved, it becomes a CISPR standard.

The **PLT Project Team** goal is to develop an amendment to the CISPR 22 to define “Limits and method of measurement of broadband telecommunication equipment over power lines”. 25 experts from different countries participate to the project.

Major milestones:

March-May 2005. France submitted a new work item for a PLT Project Team (PLT PT) within CISPR/I with the objective to continue the development of the amendment of the CISPR22 with appropriate limits and methods for PLT devices (CISPR/I/145/NP). The creation of the PLT Project Team is approved in May 2005 with 92% of positive votes (CISPR/I/156/RVN). This decision confirms that the methods and limits specified in CISPR22 are not appropriate for the PLT technology.

March 2006. CISPR/I/186/DC described the different electrical elements of the

PLT installations:

September 2006. CISPR/I/211/DC confirmed the following classification of the typical PLT installations, defined a list of equipment potentially disturbed by the PLT installations and described for each class of installation the coupling paths between the PLT transmission medium (MV or LV lines) and the non-PLC equipment potentially disturbed by the PLC installations when the risks of disturbance were the most probable.

The PLT Project Team decided to focus on the in-home PLT installations (Class ID 20 and 21) and address more tasks in parallel in order to speed up the work.

June 2007. In the meeting in Geneva, the PLT PT agreed on the baseline of Committee Draft (CD) specifying the measurement method and the limits to apply to PLT modems located inside the home.

The Project Team analyzed about 600 measurements of LCL of existing power lines in 6 different countries. No major differences were noted between the results from the different countries and the PT agreed to choose an 90th percentile of the measurement (90 % of measured installations have a measured LCL higher than that value) for the evaluation that corresponds to an LCL of 24 dB. Regarding the ISN impedances, the PT agreed on a common mode impedance value of 25 Ohms and a differential mode impedance of 100 Ohms that corresponds to the specifications of the AMN.

Regarding the limits, the PT agreed to give the possibility to use either voltage or current limits like it is the case for the measurement of telecommunication ports.

The proposed voltage limits were the voltage limits applying to the mains ports, according to CISPR 22 (Table 1 and 2) and the proposed current limits were derived for use with the new impedance stabilization network (ISN) which presents a common mode (asymmetric mode) impedance of 25 . to the PLT port under test (conversion factor is 20 log10 25 . = 28 dB).

The baseline was supported by more than two thirds of the experts present at the Geneva meeting in June. The experts supporting the baseline CD represented all interest categories affected by the scope of the amendment. In particular, the interests of the PLT industry and the interests of the protection of the radio services were both represented.

January 2008. CISPR/I/257/DC. The PLT PT decided at the meeting in Stuttgart to issue a CD based on the agreed baseline to the National Committees for comments. The comment period was of three months.

July 2008. Results of the comments on CISPR/I/257/CD

- *6 “supports”: BE, CH, ES, FR, IL, IT*
- *4 “no opposition”: CA, CN, CZ, KR*
- *1 “reduction”: JP*
- *2 “other methods”: NL (DM filter + AMN), GB (AMN + relaxation + notching)*
- *1 “no consensus”: DE*
- *8 “strong opposition” (AMN or LCL of 6 dB): AT, AU, CY, DK, FI, ZA, SE, US*

Around 50% of countries had positive comments on the document so the decision was made to continue to improve the document to increase the consensus.

A new CD will circulate in February 2009. The PLT Project Team hopes to receive even more positive comments from national committees and be able to send a CDV mid 2009 to obtain a CISPR standard ready for October 2009.

Today Notified Bodies which have the ability to give product agreement already use the CISPR/I/257/CD as state of the art.

Conclusion

Release an amendment to the CISPR 22 norm for PLT products means that interference aspects are studied and solved and national committees from many countries are giving their agreement for PLT solutions large deployment.

Release an IEEE Standard on PLC protocols means communications on the power medium is now well organized, including inhome and access applications. This well organized communication allowed the market to drastically increase without the fear of systems blocking each other.

With these two Standards, PLC will no longer be classified as a promising advance technology but just as a huge industry.

5.2 WIRELESS TECHNOLOGIES

The term "Wireless Broadband" is usually referred to technologies that use point to point or multipoint microwave connections using frequencies between 2.5 and 43 Gigahertz to send and receive signals between hub sites and end-users.

Not all of these technologies allow simultaneous wireless delivery of voice, data, and video. Those that can afford this are generally implemented in metropolitan areas and require clear line of sight between the transmitter and the receiving end.

We are going to provide an overview of the most significant wireless technologies.

5.2.1 Microwave links

The development of radio frequency (RF) technology has allowed the use of microwave links as main linkage for the communication at long distance. The use of microwave links has advantages over the laying of cables, such us the freedom from land acquisition rights and the simplicity of communication over difficult terrain. Nevertheless, it also has disadvantages since bandwidth allocation is extremely limited (bandwidth allocations of 50MHz in the carrier range 300MHz to 1GHz are typical); the use of free-space communication results in susceptibility to weather effects, particularly rain; the transmission path needs to be clear; the system is open to RF interference; and the cost of design, implementation and maintenance of microwave links is high.

The microwave links present limitations when the demand for bandwidth increases. Nowadays ther is still no profitable method to be able to increase in the same proportion the capacity of these systems.

Figure 10. Microwave antenna

Summary of characteristics:

Technology	Microwave
Simplicity of deployment	Difficult. LOS needed
Spectrum Usage	2, 4, 6, 21.3 –23.6 GHz > 40 GHz UHF(Licensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 155 Mbps per Link
Max Range	5 km
Strengths	Quick setup
Weaknesses	LOS Point to Point

Table 7. Summary Microwave

5.2.2 Multichanel Multipoint Distribution Service (MMDS)

Multichannel Multipoint Distribution Service (MMDS) is a broadcasting and communications service that operates in the ultra-high-frequency (UHF) portion of the radio spectrum between 2.1 and 2.7 GHz. MMDS is also known as wireless cable. It was designed to be a substitute for cable television (TV). Besides this, it also has applications in data communications.

In MMDS, a medium-power transmitter is located with an omnidirectional broadcast antenna at or near the highest topographical point in the intended coverage area. The workable radius can be as much as 100 km in flat terrain (significantly less in hilly or mountainous areas). Each subscriber is equipped with a small antenna, along with a converter that can be placed next to, or on top of, a conventional TV set. There is a monthly fee, similar to that for satellite TV service. An MMDS network can provide high-speed Internet access, telephone/fax, and TV together, without the constraints of cable connections

The MMDS frequency band has room for several dozen analog or digital video channels, along with narrowband channels that can be used by subscribers to transmit signals to the network. The narrowband channels were originally intended for use in an educational setting (so-called wireless classrooms). The educational application has enjoyed some success, but conventional TV viewers prefer satellite TV services, which have more channels.

MMDS has wider coverage than LMDS, up to 60 km, but has lower throughput rates. Like other broadband wireless technologies, MMDS involves costly equipment and infrastructures. However, as it is more widely adopted, it is expected that the service costs will decrease.

Figure 11. MMDS Grid Antenna

Summary of characteristics:

Technology	MMDS
Simplicity of deployment	Difficult. LOS needed
Spectrum Usage	2.1 – 2.7 GHz (Licensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 10 Mbps per BE
Max Range	100 km
Strengths	Point to multipoint NLOS Long range
Weaknesses	Low capacity Not standadized

Table 8. Summary MMDS

5.2.3 Local Multipoint Distribution Service (LMDS)

LMDS is a high bandwidth wireless networking service in the 28-31 GHz range of the frequency spectrum and has sufficient bandwidth to broadcast all the channels of direct broadcast satellite TV, all of the local over-the-air channels, and high speed full duplex data service (is used to deliver voice, data, Internet and video services). On average the distance between LMDS transmitters is approximately one mile.

LMDS (Local Multipoint Distribution Service) is a broadband wireless point-to-multipoint specification utilizing microwave communications: signals are transmitted in a point-to-multipoint or broadcast method; the wireless return path, from subscriber to the base station, is a point-to-point transmission.

Benefits:

- It's very cost effective.
- Major percentage of investment is shifted to CPE (Customer Premise Equipment) which means operator spends money on equipment only if a customer signs up.
- A very scalable architecture and it uses open industrial standards, ensuring services and expendability.
- Cost-effective network maintenance, management, and operating costs.

Figure 12. LMDS antenna

Summary of characteristics:

Technology	LMDS
Simplicity of deployment	Difficult. LOS needed
Spectrum Usage	28 – 31 GHz (Licensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 155 Mbps per Link
Max Range	4 km
Strengths	Point to multipoint Large capacity
Weaknesses	LOS Not standardized

Table 9. Summary LMDS

5.2.4 Free Space Optics (FSO)

Free-space optics (FSO), also called free-space photonics (FSP), refers to the transmission of modulated visible or infrared (IR) beams through the atmosphere to obtain broadband communications. Most frequently, laser beams are used, although non-lasing sources such as light-emitting diodes (LEDs) or IR-emitting diodes (IREDs) will serve the purpose.
The theory of FSO is essentially the same as that for fibre optic transmission. The difference is that the energy beam is collimated and sent through clear air or space from the source to the destination, rather than guided through an optical fibre. If the energy source does not produce a sufficiently parallel beam to travel the required distance, collimation can be done with lenses. At the source, the visible or IR energy is modulated with the data to be transmitted. At the destination, the beam is intercepted by a photodetector, the data is extracted from the visible or IR beam (demodulated), and the resulting signal is amplified and sent to the hardware. This technology can transmit voice, data, and video at bandwidths up to 2.5 Gbps

FSO systems can function over distances of several kilometers. As long as there is a clear line of sight between the source and the destination, communication is theoretically possible. Even if there is no direct line of sight, strategically positioned mirrors can be used to reflect the energy. The beams can pass through glass windows with little or no attenuation (as long as the windows are kept clean!).

The most common uses for this technology include:

- bypassing local-loop systems;
- interconnecting local-area network segments that are housed in buildings separated by public streets or other properties;
- carrying cellular telephone traffic from antennas to the public switched telephone network.
- deploying FSO as part of Metropolitan Area Networks (MANs);
- providing redundancy within MANs and even Wide-Area Networks in which an FSO link provides backup to an existing fibre-optic link;
- enabling a company to provide service to a customer within a few days while a more permanent fibre-optic infrastructure is laid or repaired.

Although FSO systems can be a good solution for some broadband networking needs, there are limitations. Most significant is the fact that rain, dust, snow, fog, or smog can block the transmission path and shut down the network.

Figure 13. FSO antenna

Summary of characteristics:

Technology	FSO
Simplicity of deployment	Difficult. LOS needed
Spectrum Usage	Infra-red THz region of Rf spectrum (Unlicensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 2.5 Gbps per link
Max Range	4 km
Strengths	Low setup cost Unlicensed spectrum
Weaknesses	LOS Performance is weather sensitive

Table 10. Summary FSO

5.2.5 Wireless Fidelity (WiFi)

WLAN (Wireless Local Area Network) enables subscribers to connect to the Internet from various locations without the restriction of staying indoors. It is based on the IEEE 802.11x standard and transmitting in unlicensed spectrum at 2.4 GHz. The evolution of the standard is as follows:

- 802.11, which only supported a maximum bandwidth of 2 Mbit/s

- 802.11b: supports up to 11 Mbit/s using the same 2.4 GHz range as the original 802.11 standard
- 802.11a: supports bandwidth up to 54 MBit/s and signals in a regulated 5 GHz range
- 802.11g: attempt to combine the best of both 802.11a and 802.11b. It supports bandwidth up to 54 Mbit/s, and it uses the 2.4 Ghz frequency for greater range an being backwards compatible with 802.11b
- 802.11n: the newest IEEE standard in the Wi-Fi category was designed to improve on 802.11g in the amount of bandwidth supported by utilizing multiple wireless signals and antennas (called MIMO technology) instead of one. When this standard is finalized, 802.11n connections should support data rates to a maximum of 600 Mbps. 802.11n also offers somewhat better range over earlier Wi-Fi standards due to its increased signal intensity. 802.11n equipment will be backward compatible with 802.11g gear.

It is important to describe the methods used by 802.11n to boost the capacity as compared to previous releases [19]. The techniques underneath ths capacity increase may serve as a guide to improve current PLC performance. First, 802.11n increases the number of subcarriers from 48 in 802.11g to 52, therefore increasing the throughput from 54Mbps to 58.5 Mbps. Second, 802.11n introduces a more efficient FEC (Forward Error Correction), increasing the link rate from 58.5 Mbps to 65 Mbps (from ¾ to 5/6 in coding rate).

Third, the gurad interval is reduced from 800 ns to 400 ns, boosting the throughput to 72.2 Mbps. Fourth, the introduction of MIMO provides an additional degree of capacity by using spatial multiplexing techniques. In ideal conditions, the capacity goes up linearly with each extra antenna at both ends. The maximum number of antennas in the receive and transmit antenna arrays specified by 802.11n standard is four. This allows four simultaneous 72.2 Mbps streams, giving a total throughput of 288.9 Mbps.

Finally, there is an optional feature that allows the channel bandwidth to be increased from 20 to 40 MHz. While the channel bandwidth is doubled, the number of data subcarriers is slightly more than doubled, going from 52 to 108. This yields a total channel throughput of 150Mbps. So again combining four channels with MIMO techniques an spatial multiplexing, the total throughput is 600 Mbps.

Wireless communication has a few problems that plague this service. These include data rate, distance, reliability and interferences.

Although WiFi systems can be a good solution for Local Area Networks, its limitations in distance mean that it can only be used to resolve the last mile of communications in particular cases.

Figure 14. Router WiFi

Summary of characteristics:

Technology	WiFi
Simplicity of deployment	Easy for LAN environment
Spectrum Usage	2.4, 5.7 GHz (Unlicensed ISM bands ISM: Industry,Scientific and Medical)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Depending on standard: 2, 11, 54 Mbps
Max Range	100 m
Strengths	Ethernet compliant. Standardize.
Weaknesses	For LAN applications only Security

Table 11. Summary WiFi

5.2.5.1 Business models: PLC + Wi-Fi

5.2.5.1.1 PLC Backbone based on Wi-Fi

If a public utility company wants to install a PLC system on its power grid, an analysis of the design of the power grid is necessary. In a first step it is important to get an overview over the number of transformer stations, street cabinets and the number of households in this area. The next step is to define how many headends should be installed in the area and where they should be installed. At this point it is important to remember that PLC as a typical last mile technology needs a backbone connection at the headend (e.g. in transformer stations or in street cabinets). Therefore it is useful to keep in mind where an easy and cheap connection to the backbone is practicable. Quite often it is too expensive to lay a fibre optics connection to the transformer station. In these cases one alternative is to install a Wi-Fi-system as a backbone.

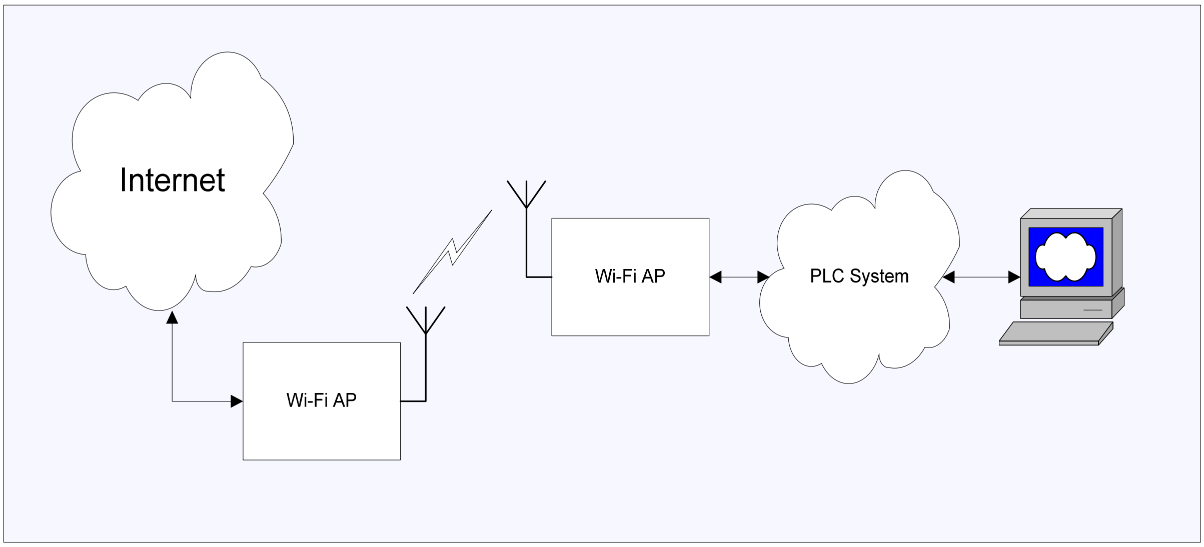


Figure 15. PLC backbone based on WiFi

5.2.5.1.2 Wi-Fi Backbone based on PLC

In more and more hotels and public buildings WLAN-(Wi-Fi) coverage or a WLAN-hotspot should be provided. In some cases especially in historic listed buildings or buildings with a lot of public foot traffic it might be difficult and expensive to install LAN-cable in the buildings to access the WLAN Access Points. Under these circumstances PLC as a backbone solution for Wi-Fi hot spots could be installed quickly and without any disturbance of the guests and the public foot traffic. PLC is a good alternative to the installation of network cable through the building.

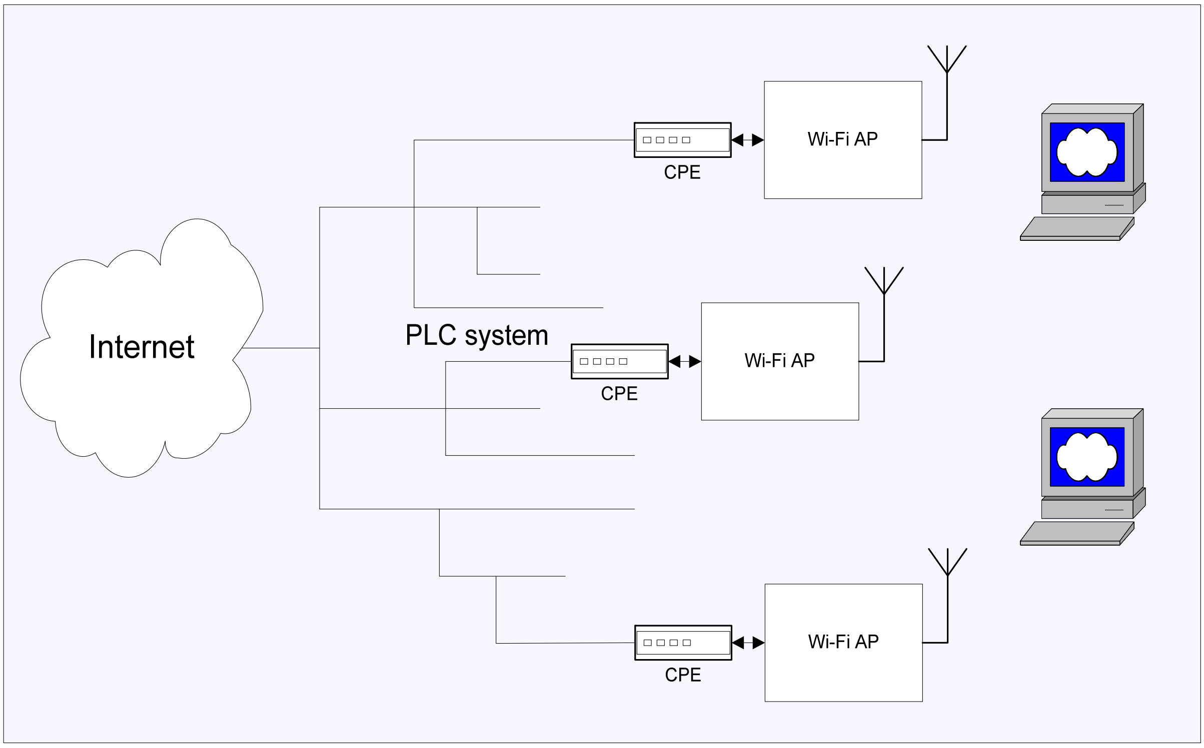


Figure 16. Wi-Fi Backbone based on PLC

5.2.5.1.3 Wi-Fi-Router as in-house extension for the customers

For internet access with xDSL or cable it is a standard application to install a Wi-Fi router behind the xDSL modem or the cable modem to make internet access available everywhere at home. The only requirement is a Wi-Fi compliant interface in the PC. Most laptops have an integrated WLAN functionality.

It is also possible to install a Wi-Fi router with a PLC CPE. Thus the internet access is available throughout the house without reinstalling the modem in another room and it is also available at the same time with different PCs in different rooms.

This makes the use easier and more comfortable for the customer.

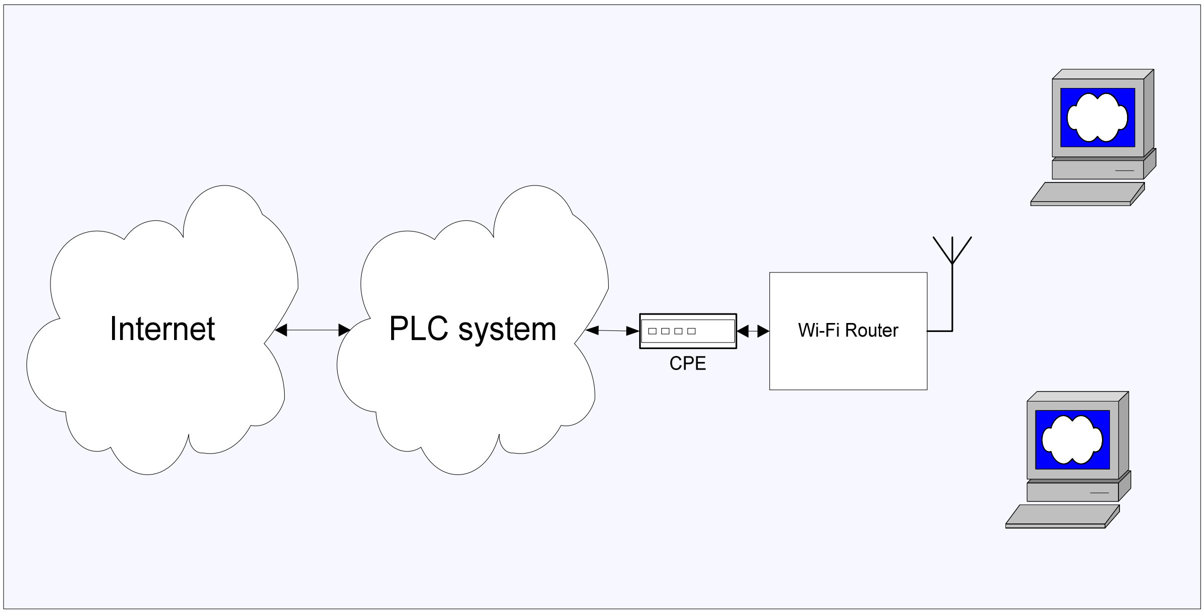


Figure 17. Wi-Fi-Router as in-house extension for the customers

5.2.5.1.4 PLC as complement of a Wi-Fi-installation

In some buildings or enterprises it is not possible to install a reliable WLAN coverage. Therefore there are different examples. One example is that there are thick concrete walls through that a WLAN communication is not possible because the attenuation of concrete walls for electromagnetic wave with a wavelength of circa 12.5 cm is very high. Most of the electromagnetic waves (in the 2.4 GHz range) will be reflected on a concrete wall. This situation can be found in some hotels where a WLAN coverage for complete building including every guest room can only realized by installing an AP in all public areas and every guest room. The same problem can be found in school buildings where the WLAN coverage for every class room is very difficult.

Another example is a steelwork where we have too many reflections of electromagnetic waves. Then the WLAN AP receives the transmitted signals very often and overlapping so that the information cannot be decoded.

In these cases a combination of WLAN for the public areas (e.g. meeting rooms in hotels or the auditorium in a school) and a PLC network for the areas where WLAN installations are too expensive or not possible.

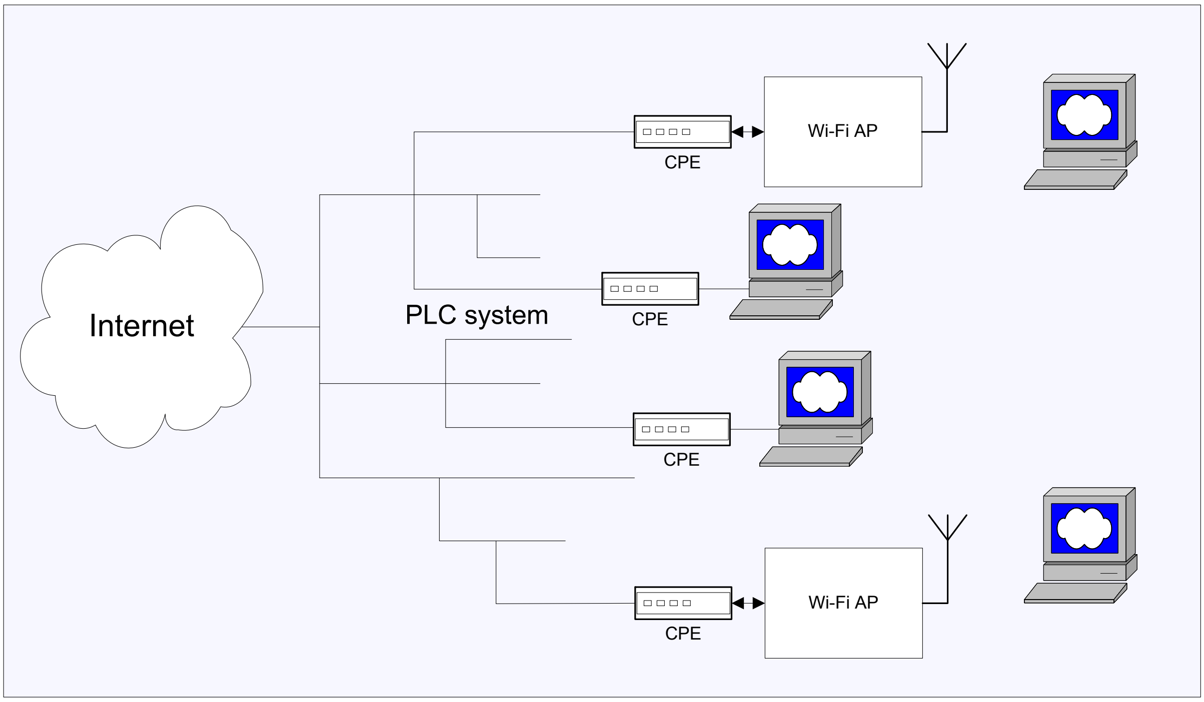


Figure 18. PLC as complement of a Wi-Fi-installation

5.2.6 Worldwide Interoperability for Microwave Access (WiMax)

WiMAX is described in IEEE 802.16 Wireless Metropolitan Area Network (MAN) standard.

A simple WiMAX system comprises of, like other radiowave systems, by two main parts: a Base Station and a Receiver. The WiMAX Base Station consists of indoor electronics and a WiMAX tower. Typically, a base station can cover up to 10 km radius (Theoretically, a base station can cover up to 50 kilometer radius or 30 miles, however practical considerations limit it to about 10 km or 6 miles). The WIMAX Receiver and antenna could be a stand-alone box or a PCMCIA card that sits in your laptop or computer. Access to a WiMAX base station is similar to accessing a Wireless Access Point in a WiFi network, but the coverage is better.

Several base stations can be connected with one another by use of high-speed backhaul microwave links. This would allow a WiMAX subscriber to roam from one base station to another base station area, similar to roaming enabled by Cellular phone companies.

Important Wireless MAN IEEE 802.16 (WiMAX) Specifications

- Range - 30-mile (50-km) radius from base station
- Speed - Up to 70 megabits per second
- Non-Line-of-sight (NLoS) between user and base station
- Frequency bands - 2 to 11 GHz and 10 to 66 GHz (licensed and unlicensed bands)

– Defines both the MAC and PHY layers and allows multiple PHY-layer specifications.

WiMAX is also expected to be more reliable than other technologies for broadband access, due to wireless nature of communication between the customer premises and the base station. This is particularly useful in developing countries where the reliability and quality of land-line communications infrastructure is often poor.

It is expected that WiMAX compliant systems will provide fixed wireless alternative to conventional DSL and Cable Internet.

Figure 19. WIMAX devices

Summary of characteristics:

Technology	WIMAX
Simplicity of deployment	Easy. NLOS needed.
Spectrum Usage	2 to 11 GHz (licensed) 10 to 66 GHz (unlicensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 70 Mbps
Max Range	Up to 50 km
Strengths	NLOS to be standardized
Weaknesses	Practical bitrate is 2 Mbps per subscriberand maximum NLOS cellsize limited to 1 – 2 km

Table 12. Summary WIMAX

Nowadays, the evolution of WiMAX is to 802.16m. The aim is to have transfer speeds of up to 1 Gbps while maintaining compatibility with legacy WiMAX radios. As in 802.11n, the technique behind this increase in capacity is the use of MIMO systems. 802.16m will meet the cellular layer requirements of IMT-Advanced next generation mobile networks, not only in higher data rates, but also in corresponding spectral efficiencies, system capacity and cell coverage as well as decreasing latency and providing Quality-of-Service while carefully considering overall system complexity.

The key features of IMT Advanced are:

- High degree of commonality of design worldwide
- Compatibility of services within IMT-Advanced and with the fixed networks
- High quality
- Small terminal suitable for worldwide use
- Worldwide roaming capability
- Capability for multimedia applications within a wide range of services and terminals

In order to make these requirements possible, the following key technologies must be implemented:

1. System related technologies
    - Voice over IP (VoIP)
    - Optimization of IP,
    - Fault-tolerant network architecture
    - Mobile platform technology
    - Security and privacy
    - Cryptography
    - Authentication and mobile electronic commerce
    - Billing
    - Intelligent data filtering
2. Access network and radio interface
    - Modulation and coding schemes
    - Multiple access schemes
    - Adaptive radio interface
    - New antenna concepts and technologies
    - Handover between different radio interfaces (vertical and horizontal)
    - Dynamic QoS control
3. Utilization of spectrum
    - Multiple Input Multiple Output (MIMO)
    - Adaptive antennas
    - Adaptive dynamic channel assignment
    - Spectrum sharing

(02.16m requirements for the air interface peak rate are 1 Gbps for nomadic conditions, and 100 Mbps in high mobility. Regarding Quality of Service requirements, the maximum bit rate for the supported profiles are:

- Very low rate Data: ≤ 16 kbps
- Low rate Data & Low Multimedia: ≤ 144 kbps
- Medium multimedia: ≤ 2 Mbps

- High multimedia: ≤ 30 Mbps
- Super high multimedia: 30 Mbps ~ 100 Mbps / 1 Gbps

A more complete description of 802.16m requirements can be found in [20].

5.2.6.1 Business Models: PLC + WiMAX

In order to describe new business models the main equipment from the WiMAX technology will be described.

The basic units in a WiMAX networks are base station (BS, as in PLC Head End, HE) and subscriber stations (SS, as for PLC customer premise equipment, CPE). The mobile CPE are called mobile subscribers (MS)

Base station produced for their purpose as an outdoor, micro or macro station. Also Subscriber stations are produced as indoor or outdoor units. Some vendors offer special adapter units for the connecting the subscriber outdoor antenna with the subscriber indoor unit (see Figure 17). Due to different applications, network structure and technological aspects (point-point, meshed etc.) the antenna differs significantly in their characteristics. The antenna can be active (power supplied) or passive (non power supplied) ones.

Figure 15 WiMAX Equipment from the vendor Alvarion [X9]

WiMAX Base station usually support connectivity to the Access Service Network by Network interfaces. The physical interfaces can be 10/100Base-T or Coax-RG6 with a DC-Supply of 40-60VDC. Ethernet will support IEE802.3 CSMA/CD with Half/Full Duplex. Coax will support the DOCSIS. The Management of BS will be done through Telnet/CLI, SNMP Interfaces and/or FTP transfer.

Figure 16 WiMAX Antenna (passive) with directional radio pattern from WiMo[X15]

Active and passive Types of Antennas are on the market. The passive antennas are connected through HF-RG/N connection with the impedance of 50Ohm. Active antennas with adapter unit are using 10/100BaseTX (IEEE802.3u) with RJ-45 connectors and DC-supply.

Figure 17 Adapter Unit between outdoor antenna and indoor network from Winetworks [X17]

Figure 18 WiMAX Antenna (passive) omni directional characteristic from BAZ [X16]

Figure 19 WiMAX Indoor unit with indoor/outdoor antenna from Winetworks [X17]

In order to identify scenarios and application a short look on planning for WiMAX installations seems to be necessary.

Due to the fact that the maximum capacity of a BS is limited on a cell the cell size may reduce to 100m [X4].

In order to get high market share the combination of WIMAX and PLC seems to be a reasonable solution, by supporting the customers by both solutions.

The location for a BS should be in a place where the cardinal points are optimal to use the most frequency band (economics of frequency) [X4].

In this case the BS may be situated where no backbone is available but supply power must always be supported and the backbone can be supplied by the power lines. Also in the urban area high building and therefore non line of sight situation becomes common.

As economical planning requires optimal customer coverage a sector oriented antenna planning have to be introduced [X4]. A possible solution can be worked out through adaptive antenna system (AAS), which is option in the standard. This technology can extend coverage and capacity [X5]. As today there seem to be two principles for AAS. The first introduce a beam forming antenna (BF) were the signal from the base station to the subscriber station will be formed, this result in higher distances of the signal. The second is done with multiple-input multiple-output (MIMO) were the signal is distributed uncorrelated which relates to higher data throughput [X6]. All this efforts seems to require planning tools for the WIMAX frequency and antenna installation to find the optimal location for the WIMAX coverage and signal strength. Today GSM tool are adapted with special WIMAX parameter in order to optimise the planning for WIMAX [X4]. It seems also that frequency planning became a factor which can not be neglected.

As we see the WIMAX antenna technology and planning is essential for the installation, in this field PLC can contribute by support with backbone data and can be used as in building communication, even though there is no frequency overlap with PLC.

WiMAX support time critical applications through connection oriented mechanism with classification, also different Quality of service mechanism are implemented as:

- real-time data transfer with fixed timing and data size
- real-time data transfer with fixed timing and variable data size
- time uncritical data, variable length and minimum bandwidth
- time uncritical data, variable length and without requirements

The IP Header type is used with integrated security mechanism, adaptive bandwidth mechanism, dynamic frequency selection, broadcast and multicast connection possibility and space time coding to transmit to multiple antennas.

5.2.6.1.1 Model A: WiMAX backbone/backhaul based on PLC connections

The general idea here is to support the WiMAX Base stations by PLC connections. This can be done with indoor and outdoor units. As shown in

Figure 20 the connectivity between WiMAX and Access Service Network could be realised by the PLC connection.

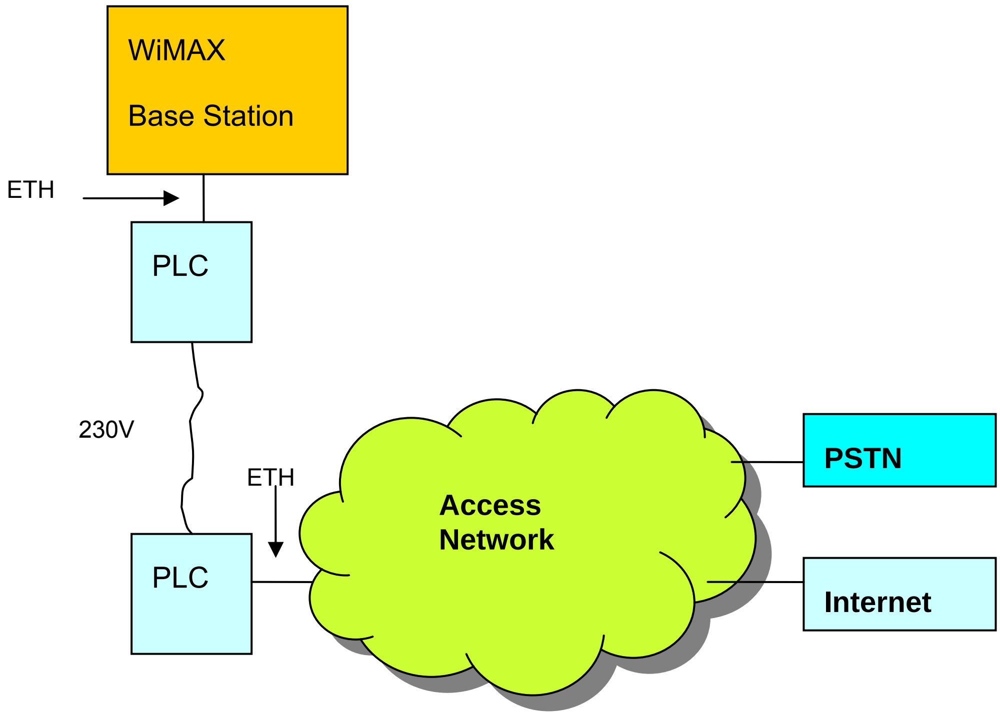


Figure 20 PLC as backbone for WiMAX BS

This situation can basically occur in every urban area where the Access Network is located street cabinets next to building. Even private networks and industrial networks can benefit from the fast deployment. The main advantage is to use existing power lines for offering new access points for the WiMAX deployment. It will be easy fast and cost effective.

5.2.6.1.2 Model B WiMAX as backbone/backhaul for PLC distribution

This Model implements the access for a PLC distribution via WiMAX. The idea is to use WiMAX point to point solution for the PLC headend access. This supports PLC installation in rural, urban and industrial and private networks. By planning PLC installation in the low voltage grid it is necessary to have access to backbone. Due to the fact that transformer stations does usually have no backbone access WiMAX with a point to point capability can reduce the installation effort and time. As shown in

Figure 21 WiMAX extends the access network to the headend of the PLC installation. With this Model the customer will supplied with PLC to the services.

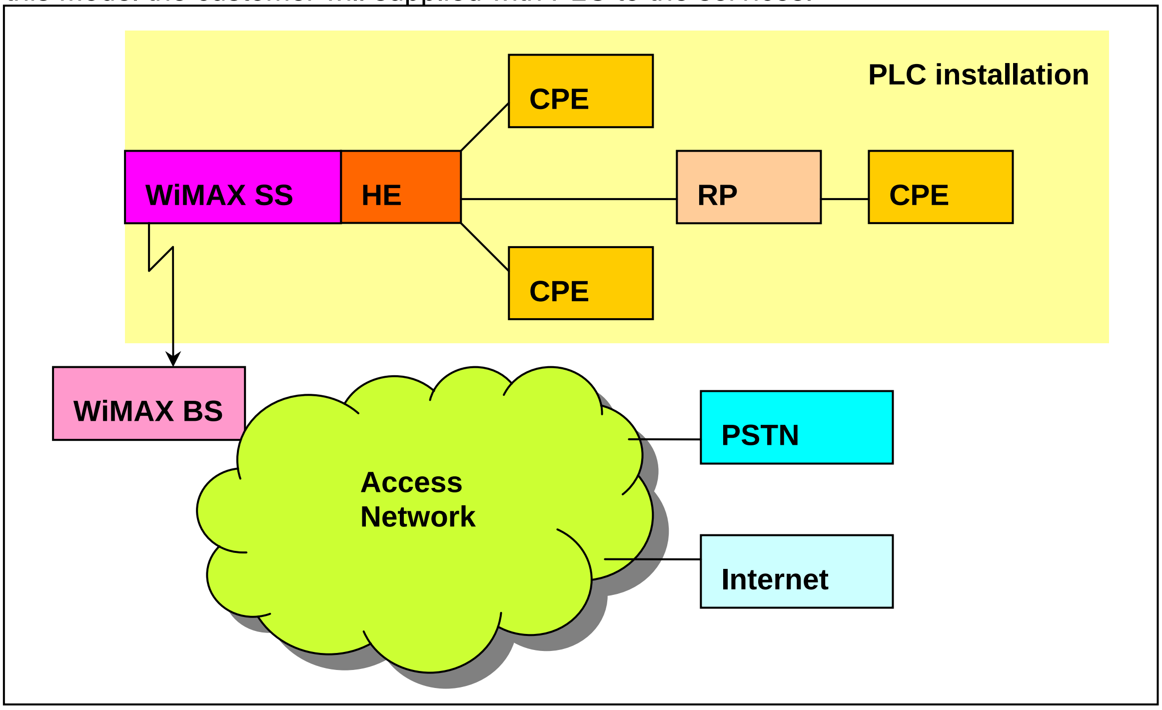


Figure 21 WiMAX as backbone/backhaul for PLC communication [X9]

5.2.6.1.3 Model C PLC as in building communication for WiMAX Subscriber Stations

WiMAX promotes the possibility of using subscriber units with indoor and outdoor capability. Unfortunately the NLOS aspects come into account in the urban areas. Indications from the market show that Base Stations have difficulties to support the theoretical distances of 500-900 m for public access in urban areas [X18]. Therefore fixed antenna connection on building seems to be a reasonable solution. The internal connection between the active antenna and the internal WiMAX components can be used to connect by PLC communication (see Figure 22). Another possibility is the extension for the WiMAX access to the internal network. This supports the IP structure all over the building through power lines.

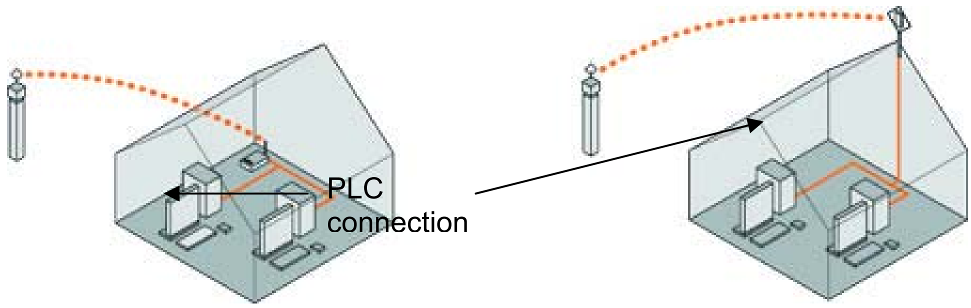


Figure 22 WiMAX connection with fixed or nomadic antenna in buildings[X3]

This Model can be used in industrial and private networks and will serve the customer by the WiMAX service with extended PLC connections.

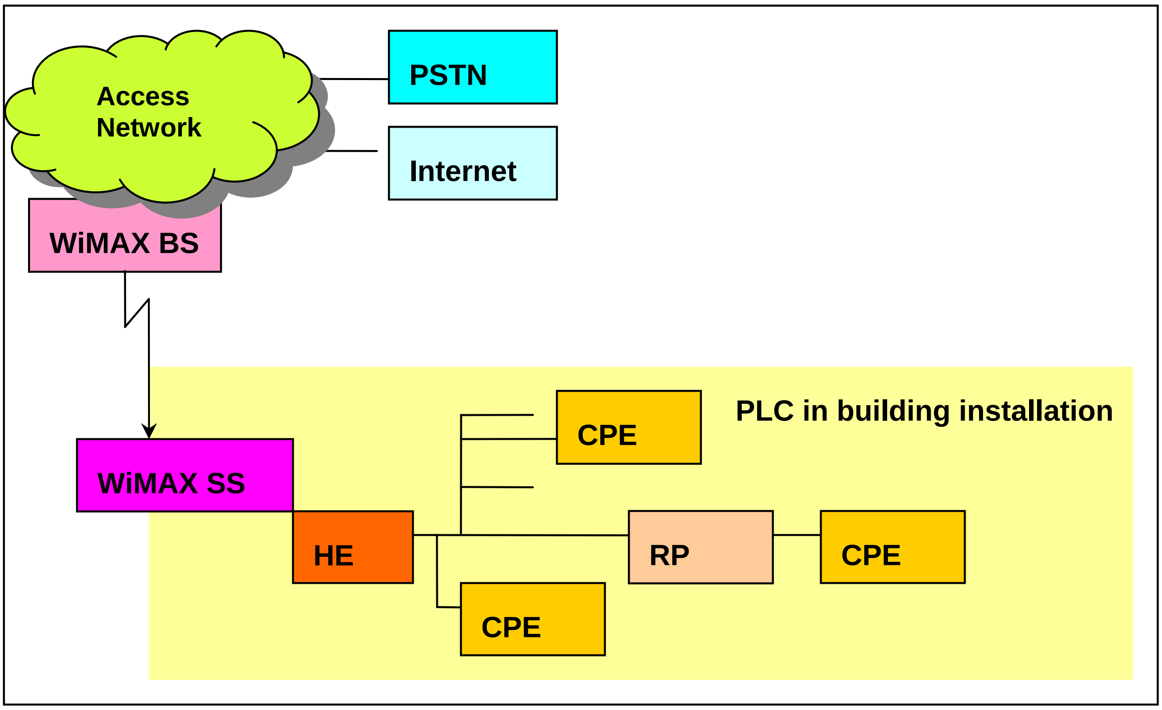


Figure 23 WiMAX Subscriber Stations with PLC in building communication

5.2.7 Satellite

Satellite access can provide broadband connectivity to rural, out of the way areas. Especially for broadcast services satellite is an unrivalled communications technology (typical applications are distance learning, video conferencing etc.).

Satellite technology has now been updated for supporting IP connectivity, with SLA and QoS features suited for sharing the bandwidth among several users and applications with different prioritisation.

Access to the satellite media is now available directly over an Ethernet interface, supporting VLAN, traffic tagging, prioritisation, etc.

The architecture for the satellite access network is typically a star, with a central hub collecting traffic from all remote sites over multiple TDMA carriers, and transmitting outbound towards them over a single large carrier.

Typical bandwidths that can be achieved can be of the order of several tens of Mbps outbound (up to 155 Mbps), and from 0 up to 2 Mbps inbound, per carrier.

Figure 20. Satellite antenna

Summary of characteristics:

Technology	Satellite
Simplicity of deployment	Easy but expensive
Spectrum Usage	Ku-, Ka-,C-, L and S-band 1.5~3.5, 3.7~6.4, 11.7~12.7, 17.3~17.8, 20~30 GHz(Licensed)
Capacity Shared?	Yes
Symmetry	Asymmetric
Capacity	Up to 155 Mbps downlink
Max Range	1000 - 36.000 km
Strengths	Large coverage Suitable for multi cast applications
Weaknesses	Expensive to build Limitedc apacity per subscriber

Table 13. Summary Satellite

5.2.8 Mobile Phone Networks (2G-3G)

3G is the third generation of mobile phone standards and technology, after 2G. It is based on the International Telecommunication Union (ITU) family of standards under the International Mobile Telecommunications programme, "IMT-2000". 3G technologies enable network operators to offer users a wider range of more advanced services while achieving greater network capacity through improved spectral efficiency. Services include wide-area wireless voice telephony and broadband wireless data, all in a mobile environment.
The most significant feature of 3G mobile technology is that it supports greater numbers of voice and data customers — especially in urban areas — and higher data rates at lower incremental cost than 2G.

Each operator acquires a license to a fixed band of the radio spectrum which is provided by the UTI for Third Generation IMT-2000 mobile services. 3G uses .5 MHz channel carrier width to deliver significantly higher data rates and increased capacity compared to 2G networks.

The .5 MHz channel carrier provides optimum use of radio resources for operators who have been granted large, continuous blocks of spectrum. On the other hand, it also helps to reduce the cost to 3G networks while being capable of providing extremely high-speed data transmission to users.

It also allows the transmission of 384 kbit/s for mobile systems and 2 Mb/s for stationary systems. 3G users are expected to have greater capacity and better spectrum efficiency, which allows them to access global roaming between different 3G networks.

Unlike IEEE 802.11 networks, 3G networks are wide area cellular telephone networks which evolved to incorporate high-speed internet access and video telephony. IEEE 802.11 networks are short range, high-bandwidth networks primarily developed for data.

Figure 21. 3G/GSM Base Station

Although 3G was successfully introduced to users in Europe, Asia, South America (Uruguay) and Africa, some issues are debated by 3G providers and users:

- Expensive input fees for the 3G service licenses
- Numerous differences in the licensing terms
- Large amount of debt currently sustained by many telecommunication companies, which makes it a challenge to build the necessary infrastructure for 3G
- Lack of member state support for financially troubled operators
- Expense of 3G phones
- Lack of buy-in by 2G mobile users for the new 3G wireless services
- Lack of coverage, because it is still a new service
- High prices of 3G mobile services in some countries, including Internet access.
- Current lack of user need for 3G voice and data services in a hand-held device

Summary of characteristics:

Technology	3G
Simplicity of deployment	Easy.
Spectrum Usage	1.92 – 1.98 GHz 2.11 – 2.17GHz (Licensed)
Capacity Shared?	Yes
Symmetry	Symmetric
Capacity	Up to 2 Mbps per mobile
Max Range	Coverage area of service provider
Strengths	Mobile terminals Ride on existing cellular infrastructure
Weaknesses	Costly spectrum Limited applications

Table 14. Summary 3G

6 COMPARISON OF TECHNOLOGIES

6.1.1 Parameters to compare. Compilation of information.

There are a number of parameters that can be evaluated in order to compare the capabilities of different technologies. Table 1and Table 2 have shown the main features of these technologies in terms of the following parameters:

- Simplicity of deployment
- Spectrum Usage: frequency band assigned;
- Capacity Shared?: informs if the available capacity must be shared between different users;
- Symmetry: describes if the technology offers balanced data rates in uplink and downlink or not;
- Capacity: bit rate available;
- Max Range: maximum distance that an access technology can reach;
- Strengths
- Weaknesses

In the following chapters, a discussion on all these aspects is included.

6.1.2 Comparison of capabilities

Figure 10 shows a global comparison between fixed line and wireless access technologies. The table provides a general overview of all the technologies under study including the most important features. In many cases, the values of the parameters within each technology are variable and depends on different factors (interference, modulation, etc.), and the table shows the most typical values.

	Technology	Normalization/ Standardization	Physical medium	Topology	Terminals	Range
Wireless technologies	Satellite	DVB, ETSI	Radio, 11-14 GHZ, (Ku), 20-30 GHz (Ka)	Multipoint	Fixed (also mobile with low kbit/s)	Line of Sight
	UMTS	3GPP	Radio, 1.7-2.2 GHz	Multipoint	Mobile	50 m-3 km
	WLAN	IEEE 802.11, ETSI	Radio, 2.4 GHz (.11b and .11g), 5 GHz (.11a)	Multipoint	Mobile	50-150 m
	DTT	DVB, ETSI	Radio (UHF)	Multipoint	Fixed	32 km
	LMDS/ WiMax	IEEE 802.16, ETSI	Radio, 3 GHz, 26 GHz and above	Multipoint	Fixed	Line of Sight, 3 km (26 GHz), 8 km (3.5 GHz)
Fixed line technologies	HFC	DOCSIS, DVB	Fiber and coaxial	Multipoint	Fixed	40 km
	FTTX	FSAN, ITU-T	Optical fiber w/o twisted cooper line	Point-to-point or multipoint	Fixed	20 km
	xDSL	ITU-T, ETSI	Twisted pair	Point-to-point	Fixed	300 m-6 km
	PLC	PLC Forum, CENELEC, ETSI, IEEE	Medium and low voltage powerlines	Multipoint	Fixed	200 m (in low voltage)
	EFM	IEEE 802.3ah	Twisted pair or fiber	Point-to-point or multipoint	Fixed	750 m-2.7 km (using twisted pair)

Table 15. General comparison of access technologies ([6], updated).

Figure 22 shows the coverage versus bit rate analysis for access technologies. The graph must be interpreted qualitatively, as the exact bit rate for each technology varies (this is the case for example of xDSL). Current PLC technology offers a throughput of 200 Mbits/s: in the access segment, this capacity must be shared between all the customers, but in in-home, the entire capacity can be used for one service. In the case of WLAN, actual bit rates reach 54 Mbit/s, but the implementation of MIMO (Multiple Input Multiple Output) systems in the terminals (802.11n standard and Pre-n equipment) doubles the capacity.

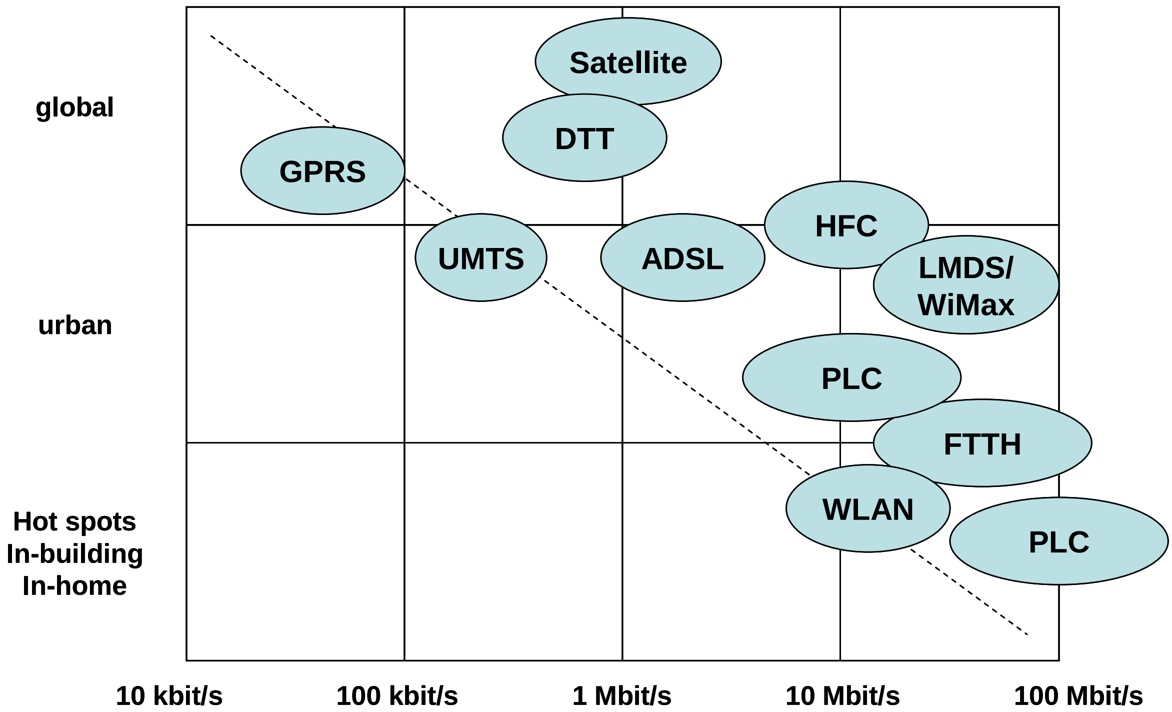


Figure 22. Coverage versus bit rate analysis for access technologies ([6], updated).

Figure 23 compares fiber, wireless and powerlines in terms of availability, affordability and bandwidth. In coverage, both wireless and powerlines offer similar performance, with a a range larger than optical fiber. In terms of affordability, the same behaviour is observed, although wireless provides the best performance. Finally, in terms of bandwidth, fiber slightly outperforms powerlines and wireless technologies offer the worst results. As well, the bandwidth achieved in wireless connection depends in general on a number of factors such as the distance to the access point and interference.

From the figure, it is clear that PLC gives an optimal trade-off between coverage, bandwidth and affordability as compared to other access technologies.

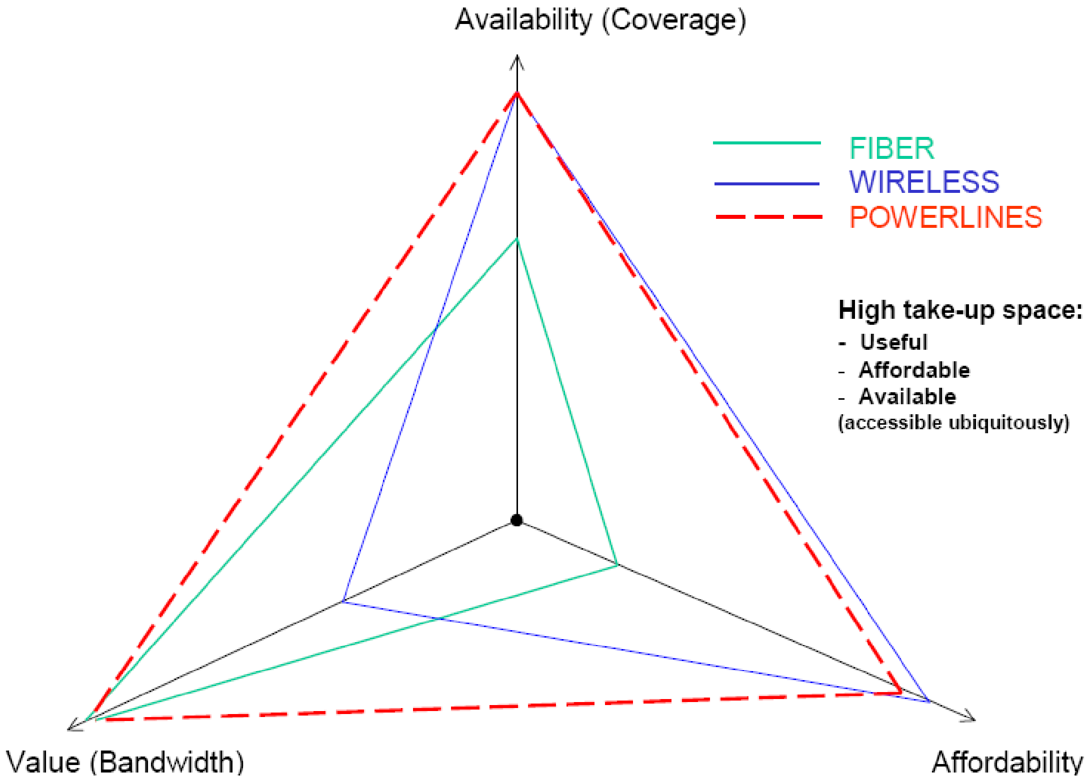


Figure 23. Comparison of fiber, wireless and powerline technologies [7].

The CAPEX (Capital Expenditure) comparison includes an analysis of PLC in 2002 and the previsions for 2005, taking into consideration reductions in the price of the equipment. Figure 24 shows the qualitative real competitive potential of the PLC technology as a function of penetration percentage. The curve for the future PLC is called PLC 2005; although the year in which the expected price reductions will be achieved will depend on the regulatory and standardisation efforts realised. It is also important to mention that the potential for further important price reductions for PLC equipment should be superior to all other fixed line technologies analysed in the figure, as they are presently in the commercial maturity phase.

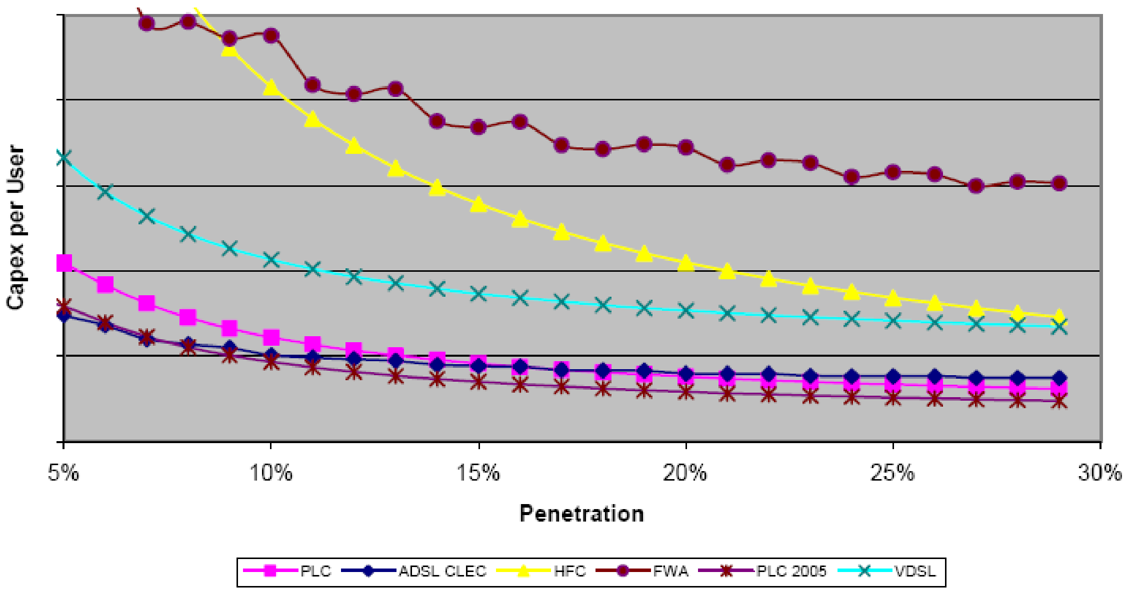


Figure 24. Comparison of Access Technology CAPEX [4].

Similarly, the OPEX (operational Expenditure) obtained for PLC demonstrates its inherent advantages as a technology based on already deployed infrastructure (Figure 25). The OPEX per user for xDSL technologies is higher than in PLC due to the unbundling costs and the maintenance of equipment (mainly for VDSL) [4].

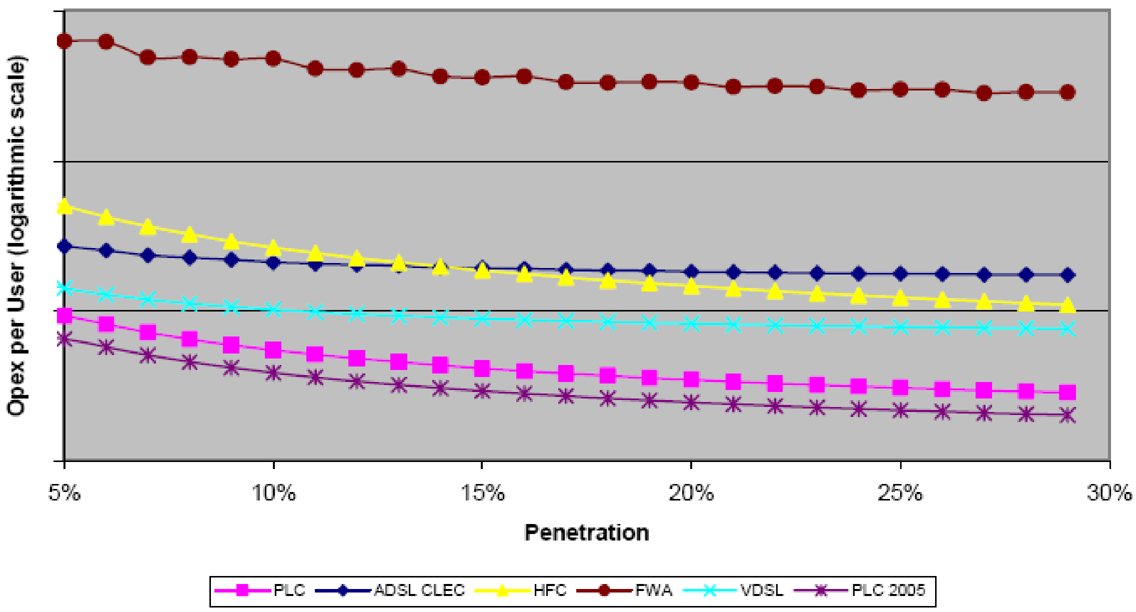


Figure 25. Comparison of Access Technology OPEX [4].

It is possible to evaluate how adequate the various technologies are for specific market segments (i.e. Residential, SOHO, SME and Corporate) and particular niches. The balance of service capacity versus deployment costs and timelines places technologies with existing infrastructure (xDSL, PLC) competitively in urban and suburban markets. HFC and FWA will be the first technologies to lose market share to FTTB as it gains relevance at first in smaller business and eventually residential markets.

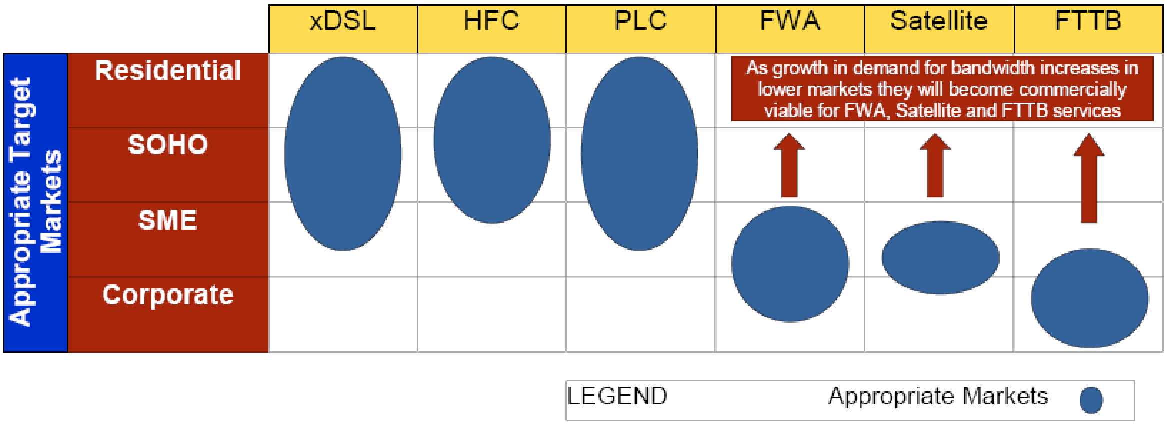


Figure 26. Appropriate target market segments by customer type.

Figure 27 shows the most adequate market segments where each access technology can operate. Each technology is likely to remain relatively competitive in the niche segments identified.In the case of urban scenarios, FWA, HFC and FTTB are more appropriate for access; however, for combining access and in-home distribution PLC is the most adequate technology, or a combination of PLC with other access technology.

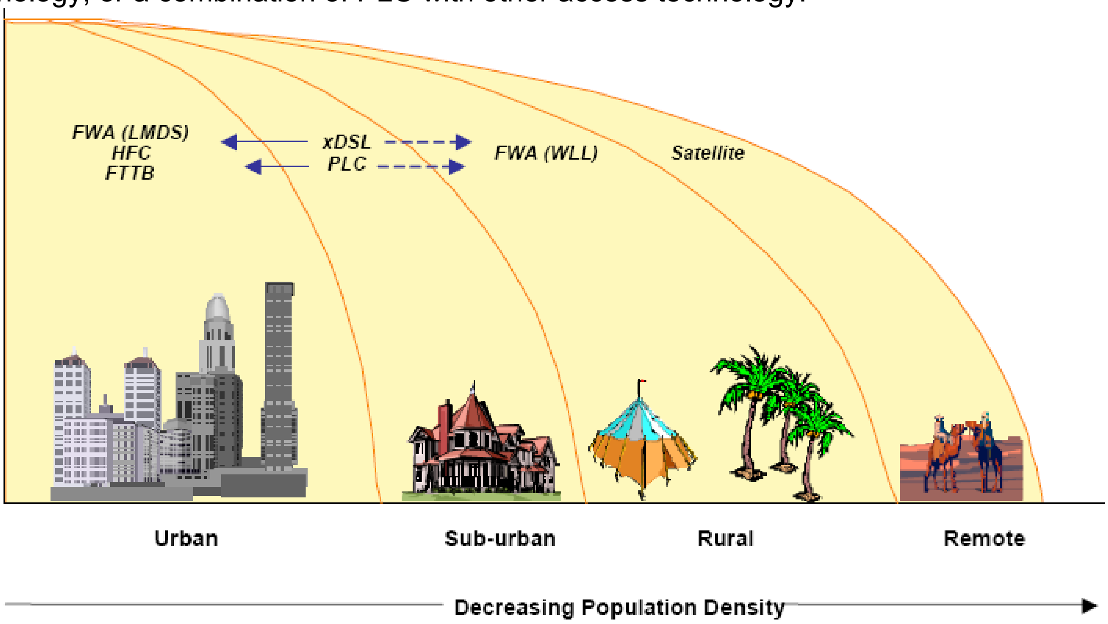


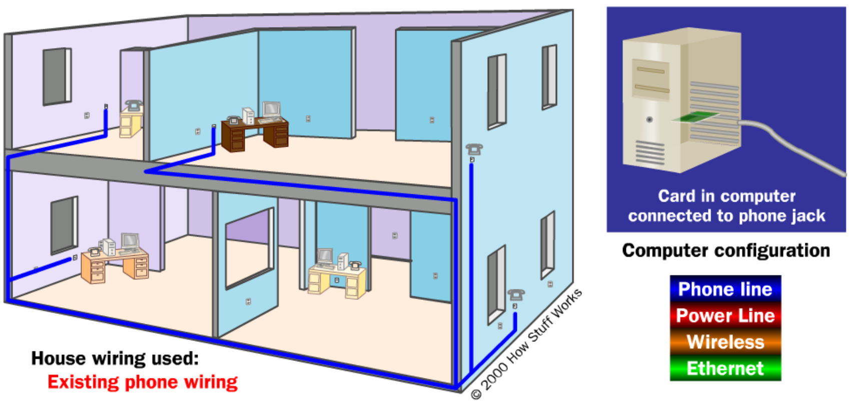
Figure 27. Appropriate market segments by population density.

6.1.3 PLC Strengths

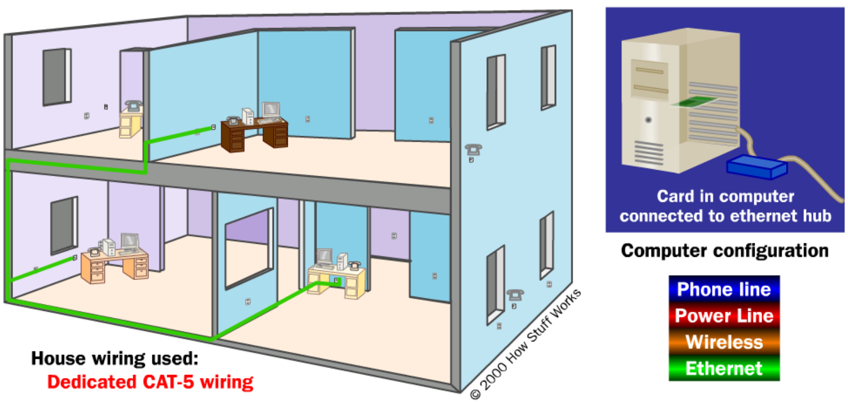
Compared to other access technologies, PLC offers a number of strengths that makes it differential.

Ubiquity: This is perhaps the most differential feature of PLC as compared to other technologies, and applies to both indoor and outdoor scenarios. Electric power line penetration is at least three times higher than telephony lines, including remote sites, meaning that the electric power grid provides a perfect communications platform because it is the most extensive network in the world. Therefore, the number of potential customers is significantly higher than with other technologies. In many areas of central Europe, fixed line penetration may be only 20% of homes or less, so that the barriers to broadband deployment using other wire line technologies in these areas are high.

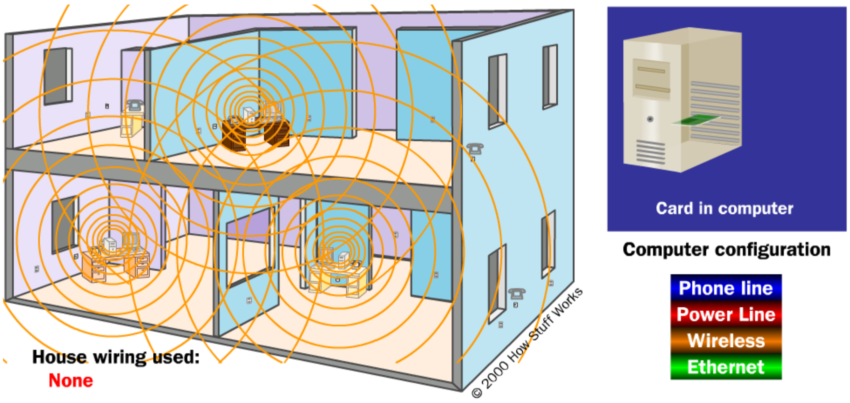
In-home distribution: due to the inherent topology in in-home scenarios, PLC constitutes an optimal technology to provide services to any point within a house without installing new cables. Using this feature, PLC constitutes a good candidate to extend the access technology to any other dependency in-home (the number of plugs in a house varies from 10 to 40). Figure 28 compares the defaults infrastructure installation between phone wiring, CAT-5 wiring, WLAN and PLC for an in-home distribution.



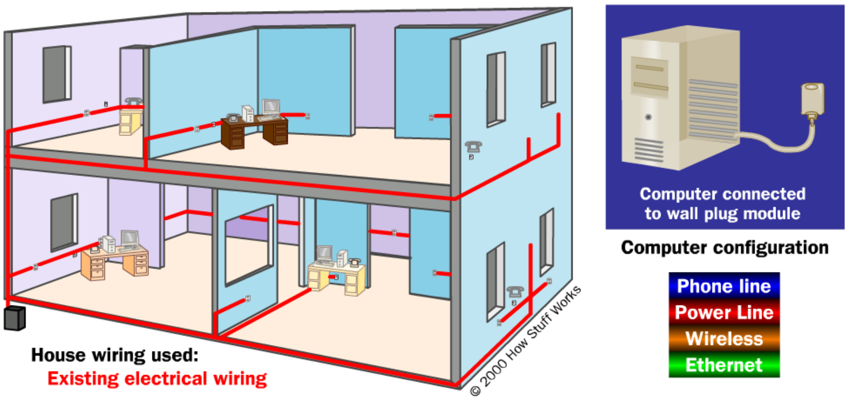
(a) Phone wiring



(b) CAT-5 wiring



(c) WLAN



(d) Powerlines

Figure 28. Default infrastructure installation for different technologies to provide services in in-home scenarios [13].

Some chips allow the AV distribution in in-home scenarios. One example is the DSS9010 chip from DS2 [8], an optimized chip that enables high-speed video and data communications over the existing domestic power cables. The DSS9010 supports transmission speeds in excess of 200 Mbps and advanced features like QoS management, multicast and network isolation using 3DES encryption. Another important feature is the plug&play autoconfiguration.

Other commercial system named as SlingboxTM [10], a device that allows consumers to access their living room television programming at any time, from any location, using displays such as laptops and desktop PCs, handheld computers and smartphones. With the Slingbox, users can see live TV via their home cable box or satellite receiver, or programs recorded on their digital video recorder (DVR).

Figure 29 shows the SecureView Box, a device family that transmits the video signals over the existing powerlines in-home in real-time, eliminating the need for cables running all over the place [9]. The customer just needs to plug the video source (like a camera) into the

SecureView transmitter, and plug it into the wall. Next, plug the SecureView receiver into the wall in the room where the customer wants to watch the video, and connect the video output to the Video In port on your TV or VCR. Another possible application of S-Box is video surveillance in office scenarios.

Figure 29. SecureView S-Box [9].

As an example, it is important to mention the case of Imagenio, the platform used by Telefonica to provide triple play services. Although Telefonica use the copper lines to provide access via xDSL, an option is offered to distribute the signal using in-home powerlines using PLC-Ethernet adapters (Figure 30). The range in an in-home scenario is 300 m with 85 Mbps [11].

Figure 30. Distribution of Imagenio using in in-home powerlines.

In-home powerlines constitute a home-network system that provides an useful communications network inside houses using the existing electrical infrastructure to provide other services in addition to AV distribution. Its main application is the development of new “Home Area Networks” which could deliver:

- “Home networking”: access points to all PLC services all over the user’s home
- “Home automation” services: lighting, air conditioning and heating control, energy management, automatic window shades, etc.
- Security: safety alarms, security sensors

Cost: the use of electric power lines as the physical transmission media eliminates the need of deploying new infrastructure. This makes PLC technology to have a reduced deployment costs, as the operator only needs to install repeaters, couplers and user equipment. By using the available power transmission and distribution infrastructure the CAPEX costs are reduced since only appropriate system level developments have to be done to reach the customers, independent of their location.

Compared to some DSL services, the customer do not have to pay for leasing the line, which is a requirement imposed by some DSL operators.

Environmental impact: related to the previous paragraph, the installation of PLC does not have a significant impact on the environment. In the case of wireless access technologies such as WiMax, antennas are not required either in the customer premises or the base station. Compared to other wired technologies such as cable, no civil work is required. As well, the problem of interferences has been minimized in the previous years with the development of new coupling and injection techniques.

Mature technology: although the lack of a global PLC Standard has slowed down the deployment, there a re a number of commercial solutions that makes PLC a mature technology that can operate in a number of scenarios. The modulation, security and QoS monitoring employed by commercial systems make PLC system robust in different scenarios where a number of interferences, noise and channel impairments appear.

PLC is now mature and ready to be standardized worldwide within an international body of standardization, and a number of international institutions are working together on the issues of interoperability and coexistence of different PLC services using a common electrical network [3].

Scalability: scalability makes reference to the flexibility of PLC to install the head-end for interconnection to the backbone (fiber, cable, satellite, etc.). The usual parameter to install the head-end is the amount of traffic or number of users. In case of PLC, depending on the number of users, the head-end can be located in the high voltage transformer sites (low penetration), medium voltage transformers (medium penetration) or some repeaters can be installed within the low voltage, if the penetration is high. Figure 31 shows the deployment scenarios for different penetration scenarios. It can be seen that in high penetration situations, the backbone connection must be extended only to the locations with larger demand. In many countries, fiber can be found in many MV/LV stations, so that the cost is not increased by the fiber installation.

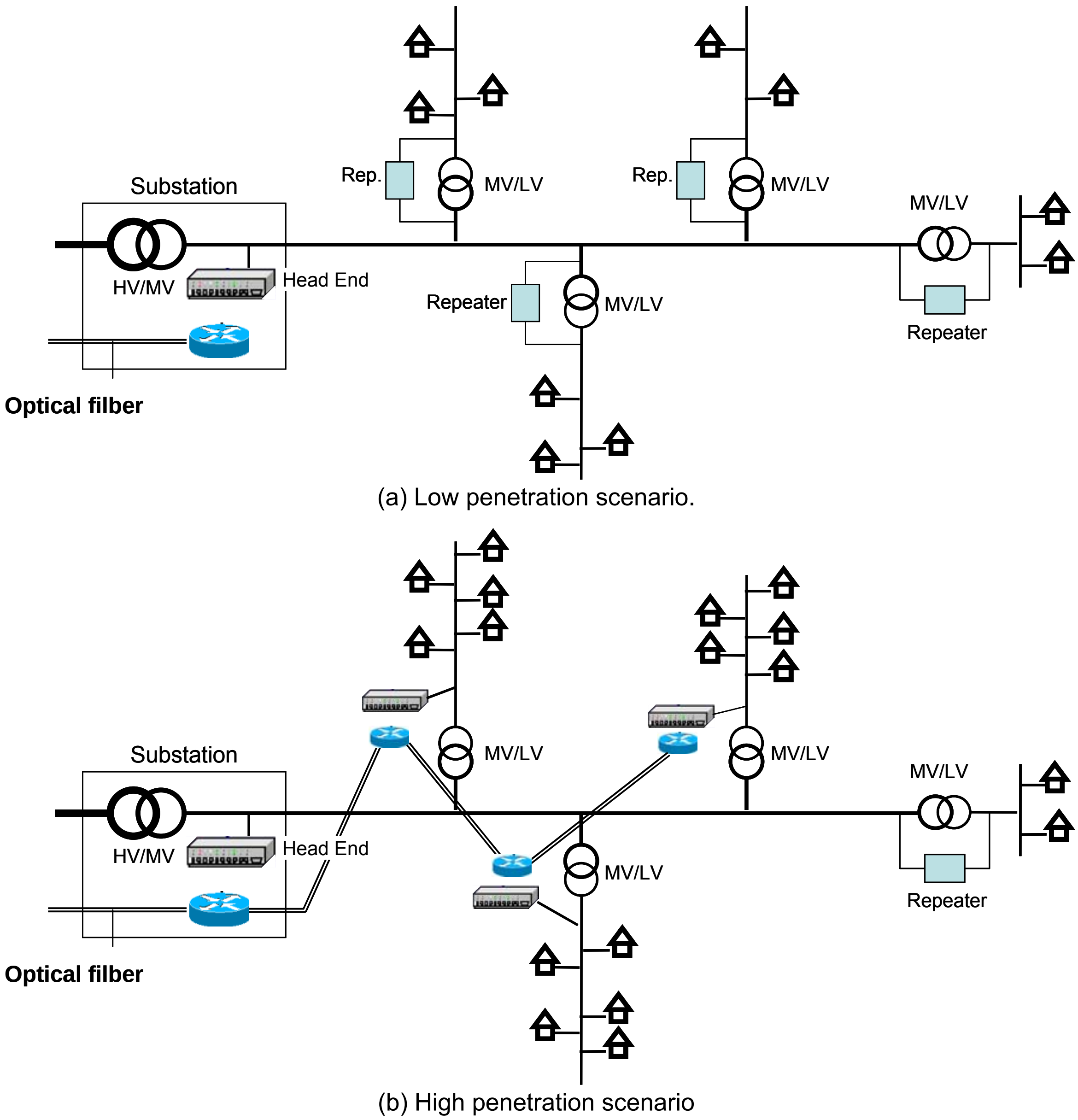


Figure 31. Deployment of PLC for different penetration scenarios.

Moreover, the traffic received in a transformer can be segmented between parallel networks using the three phases and neutral.

Easy integration with other technologies: PLC equipment can be easily integrated with other technologies. There are numerous examples of integration available. Figure 32 shows some the coexistence between LAN, WLAN and PLC technologies as seen by Ovislink [12].

Figure 32. Coexistence between LAN, WLAN and LC technologies (left) and PL-RJ45 adapter (right).

In [18], a satellite backbone is used to provide Internet access via PLC. The topology of power lines within a story building allows different users to share the same physical medium for access. The combination of satellite and wireless technologies can provide a cost effective solution for Internet access. The installation of a VSAT network with multiple terminals is an expensive solution. However, the use of wireless backhauls and WLAN access points reduce the cost for VSAT operators and service providers by extending their range of operations.

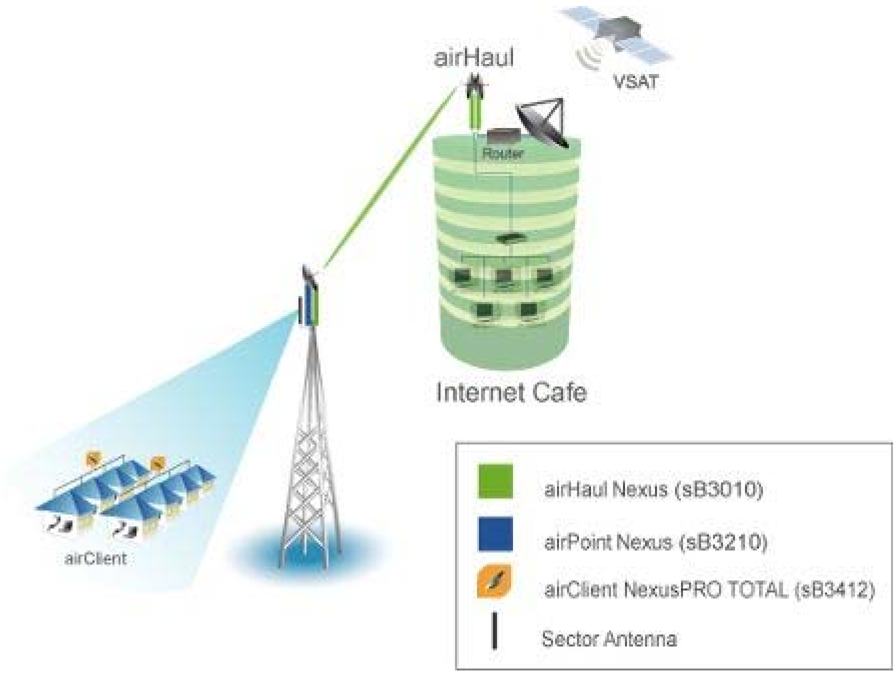


Figure 33. Satellite + PLC

Moreover, Amperion provides a solution for integrating PLC and WLAN using Amperion Connect^{TM} and Power WiFi **¡Error! No se encuentra el origen de la referencia.**. Using these technologies, PLC and WiFi are integrated to provide broadband access to the end user.

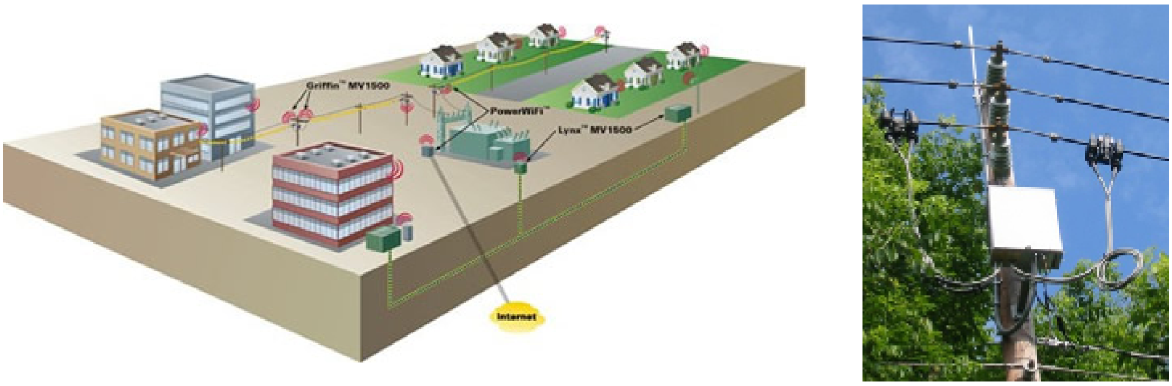


Figure 34. Network architecture of Amperion Connect^{TM} (left) and Amperion Griffin^{TM} solution (right).

New business models, services and applications: PLC technology has the possibility to implement both communications services in the access and in-home and also applications useful for the electric power utilities, "smart energy consumption", etc. Moreover, the deployment of PLC over existing powerlines for its use in in-vehicle scenarios is a promising solution for applications such as mechatronics (communications between sensors and actuators, with speeds of 10 kbit/s), telematics (digitized voice, internet, navigation trucktrailer, with speeds in the range of 10 kbit/s to 1 Mbits/s) and multimedia (CD quality music, entertainment systems, over 1 Mbit/s) [17]. In [16], an application of powerline communication for the Common Airborne Instrumentation System (CAIS) on board aircraft is described.

PLC technology opens the field to different business models that can be developed by the utilities to find synergies with other companies such as Telcos or ISPs:

- **Model#1 Full Service Provider**: The utility builds its powerline infrastructure and runs CBPL services. This model requires a high investment, implies some risk, but the return of investment (ROI).
- **Model#2 Dark Cable Provider**: The utility builds and rents its CBPL network to one or several Service Provider(s), and signs a Service Level Agreement (SLA) with the Service Provider(s). This model implies lower investment, risk and ROI.
- **Model#3 Right of Way Provider**: The utility offers the use of its electrical distribution network to Service Provider(s), who is(are) building and operating the CBPL service. In this case, both the risk and the ROI are low.

All these business models, along with the EU telecom policy based on improvement of communication infrastructure and offering competitive, high speed Internet access, are enough to ensure competition in the provision of networks and services.

Apart from business models, utilities can implement a number of additional services using PLC. The possible PLC applications for the utility could include automatic meter-reading (AMR), demand side management, outage notification, distribution transformer overload analysis, phase loss monitoring, fault characterization, and several others. Additional applications such as remote reading, telecontrol of transformer substations, theft detection, prevention of unauthorized access to the meter, remote change of the contractual parameters, or the remote disconnection for safety reasons.

Figure 35 shows the service model for the utility company using a remote metering application whereby each household's charges are determined on a slot-by-slot basis. As well, a switch ON/OFF actuation can be operated remotely from the central offices of the utility.

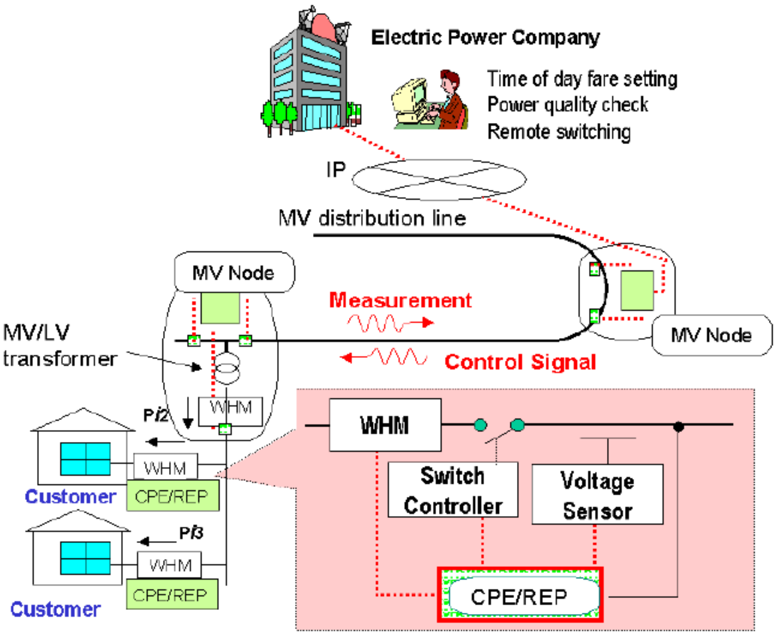


Figure 35. Service model for the utility company.

Apart from powerlines, it is important to mention that PLC technology can make use of existing non-communicative infrastructure. It means that PLC can be applied in roads, railroad rails and gas pipelines, as well as in the metallic wiring pre-installed within automobiles, vessels and even in aircrafts. These possibilities open a number of differential applications and service forms for PLC.

Social impact: thanks to the ubiquity of powerlines and the bandwidth offered by current systems, PLC improves the Internet access penetration and takes triple-play services to rural and remote areas. Therefore, services such as eGovernment, eHealth and eCommerce are made accessible to a large percentage of population. PLC can push to make the Broadband for all a reality in the next years.

Security: in spite of being a shared medium, the communications over powerlines are encrypted (using 3DES in the case of OPERA) so that the access to the information privacy of the users is guaranteed. Therefore, the level of privacy and security are not less than in other technologies.

Interference: in the initial steps of PLC deployment, amateur radio users were not confident of PLC as a potential interference source. A number of measurement campaigns demonstrated that no interference was produced if coupling is performed adequately. New coupling methods minimize the risk of PLC signal to interfere with legacy radio systems. Moreover, most of existing powerlines are deployed underground, so that no interference is produced.

In case of wireless access technologies, coordination between frequency bands used by different system is required. When the growth of demand requires new frequency bands, interference problems may appear. These days, there is a debate between satellite services using C band and the proposal of next-generation broadband wireless access and IMT 2000 services to extend their services to the lower part of C-band (3.4 to 3.7 GHz). If satellite services using C band are reallocated, a number of existing satellite services will be affected such as telehealth, rural telecenters, cyber cafes, post offices, air traffic control, small and medium enterprises, oil and gas concerns, mining, forestry, banking and other financial services [2].

6.1.4 PLC Services

The current status of PLC technology permits the implementation of a wide range of services [5]:

- Broadband Internet access: the maximum transmission rate offered by PLC devices nowadays is 200 Mbit/s;

- Telephony (VoIP): thanks to the priority scheduling of PLC, VoIP is prioritized and is reaching the quality of service traditional switched telephony. Moreover, another advantage is the fact that phone calls located in the same distribution network do not need to be switched to other operators in the PSTN;

- Applications for the utility: this group of services makes PLC differential compared to other access technologies. The main applications for the utility are AMR (Automated Meter Reading), demand side management, outage notification, distribution transformer overload analysis, phase loss monitoring, and fault characterization. Other would include telecontrol of transformer stations, billing on real readings, remote change of contractual parameters, theft detection, load forecasting. All these applications would provide enhancements in the service to the end users, such as flexibility of billing period, reliable billing, flexible tariff structure, increase of comfort and consumption optimization, and an improvement in the safety thanks to the possibility of remote disconnection.

Other applications can be provided thanks to the ubiquity and capacity of PLC. As an example, the PLC network can be used as Internet backbone, complementing other access technologies such as Wi-Fi and UMTS. The bandwidth provided by PLC can also be employed to provide broadband services with high quality of service requirements, such as HDTV, on-line gaming, videoconferencing and video and music on demand.

In the in-home domain, PLC can contribute to home networking as any plug can be converted to an access point, home automation services (lighting, air conditioning and heating control, energy management, automatic window shades, etc.), and increase safety (alarms, sensors, etc.).

7 TEST CASES

7.1 PLC + WiMAX

WiMAX and PLC are both emerging technologies that provide broadband data access. WiMAX is a wireless technology designed to provide an alternative to DSL and cable to deliver broadband customer connectivity. In most of the present early stage WiMAX deployments in Europe, the technology is also employed to provide intermediate backhaul connections to aggregated broadband access service hubs. The potential is for WiMAX to provide relatively high data rates and seamless roaming for stationary and mobile data stations.

On the other hand, PLC is a cable-based infrastructure that can provide broadband data flexibly at relatively low cost, particularly to areas that lack the required telecommunications infrastructure. PLC achieves this by utilizing the existing power network cabling and thus using an infrastructure that goes everywhere data is required.

Looking at the two technologies and the possible implementations, we realize that there are many possible interoperability scenarios. This section suggests two schemes that might prove offer increased value through they joint application.

Any decision regarding the most appropriate scenario for a particular requirement will depend on many factors regarding the specifics of the geography, topology, service level requirements, availability of backhaul etc.

7.1.1 Scenarios

7.1.1.1 WiMAX as Backhaul

In this first scenario WiMAX acts as a backhaul technology providing high speed data connectivity in the concept of point to multi-point. As shown in the diagram in Figure 36, a WiMAX access point connects to multiple stations across the region providing backhaul for MV/LV PLC extension and data provision.

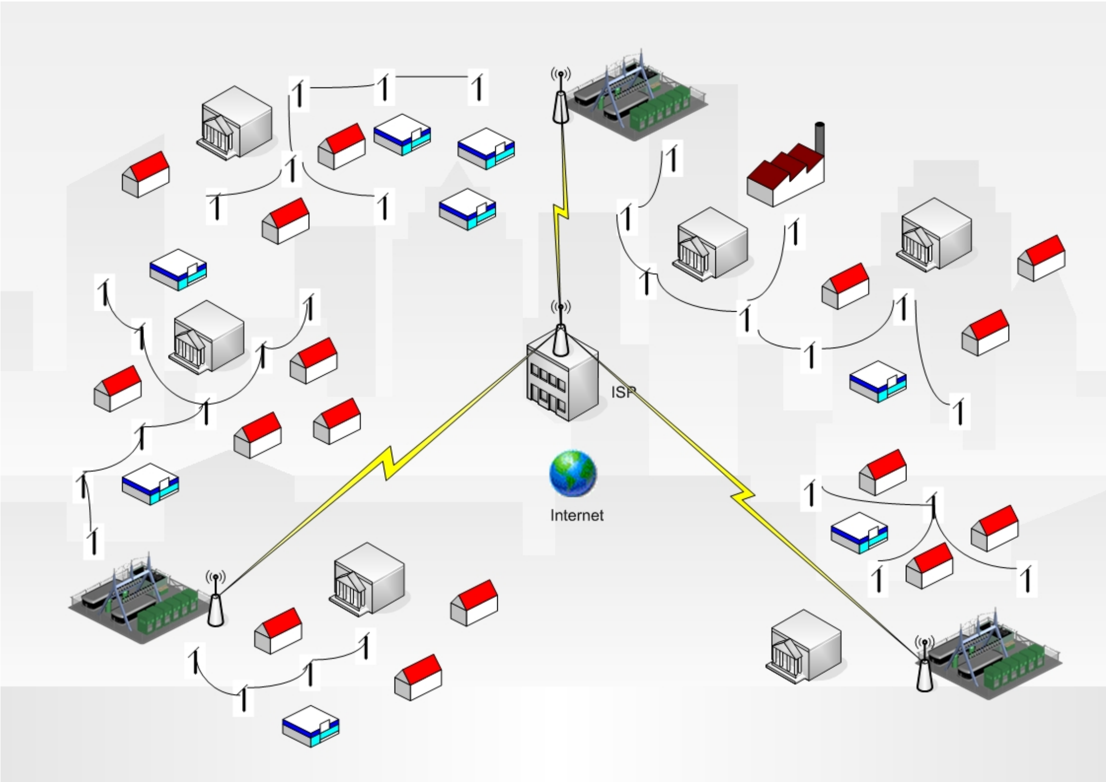


Figure 36. WiMAX Backhaul application.

In Figure 36 the backhaul connection is delivered via fiber to the ISP central offices. That backhaul is extended from the fiber network and made available to the PLC infrastructure via Point to Multi point WiMAX links to the HV/MV substations. From that point the data is injected into the MV/LV network and is delivered to the end user via various methods.

The requirements to implement this scenario are:

1. Fiber POP infrastructure to the ISP premises.
2. Point to multi-point WiMAX connectivity available

This scenario has the following potential advantages:

1. Improved physical performances inside the building.
2. Reduced frequencies are necessary for the PLC; therefore better performances can be obtained with the optimization of the outdoor links.
3. Potential to cover high vertical buildings with multiple last mile solutions.

7.1.1.2 PLC as Backhaul

In this second scenario PLC acts as backhaul to WiMAX nodes that need to be placed deep inside a densely populated area. In this scenario the existing fiber infrastructure of the power utility is utilized to the maximum since that is the starting point of the network. The MV network is then used as a backhaul to carry the data to the designated places where the WiMAX units will be installed. In this case we create WiMAX hot spots in various part of the city covering the area with data as shown in Figure 37.

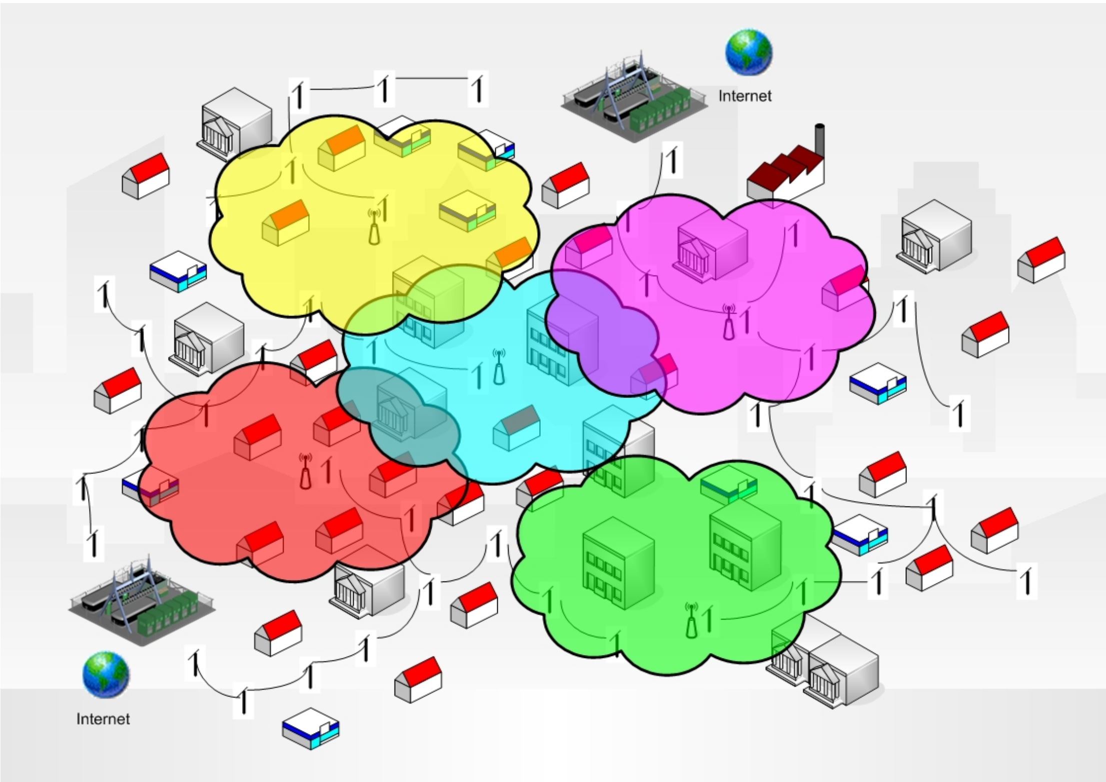


Figure 37. PLC as Backhaul

The requirements to implement this scenario are:

1. Backbone connection present in a central area with Cooper infrastructure that reaches the Power Transformers or fiber infrastructure POP at the HV/MV substation.
2. Overhead network capability for mounting of the WiMAX stations.

This scenario has the following advantages:

1. lower backbone implementation costs
2. roaming and outdoor data capability
3. scalable bandwidth growth in the number of WiMAX stations.

7.2 PLC + WLAN

PLC and WLAN are different and flexible technologies that can be combined in a variety of ways. WLAN can be used inside the PLC architecture by replacing parts of the system by WLAN links, it can also be used to interconnect PLC to Internet and PLC can be used as the Distribution System of a WLAN network. Finally, PLC and WLAN can be combined in a system to provide flexible Internet access, even facilitating the fixed-mobile integration.

Many scenarios are possible. Here we have chosen the ones we have judged to be more useful and the following paragraphs detail these different scenarios.

7.2.1 Scenarios

In this section different combination scenarios are shown. They are classified based on the point of integration between PLC and WLAN connections. A description of how would each scenario be useful is also included as well as its advantages and implementation requirements. Figure 38 details the elements used in the other figures of chapter 7.2.

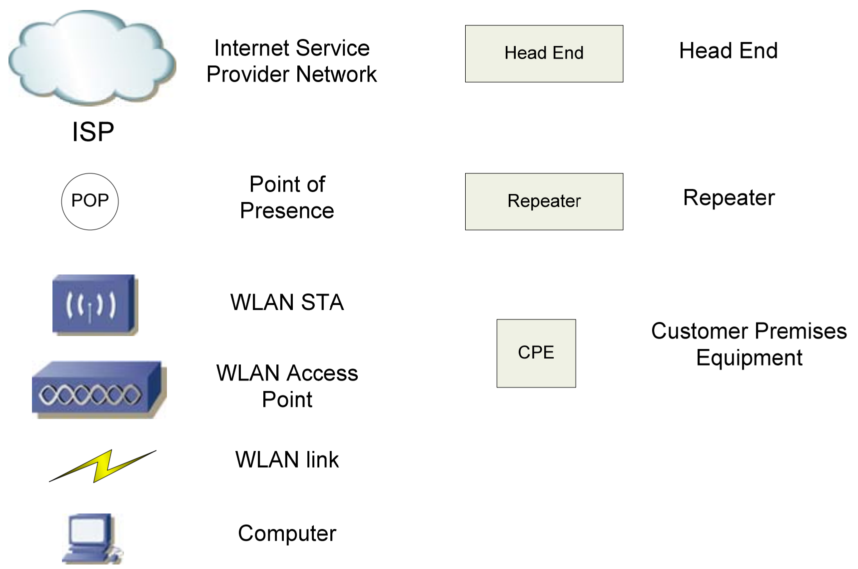


Figure 38. Definition of diagram elements.

7.2.1.1 Scenario 1. WLAN connecting the PLC system to Internet and ISPs

7.2.1.1.1 Description of the scenario 1

In this scenario, there is a WLAN connection in the Head End (HE) that is used to connect the PLC system to the Internet and the ISPs. There are two possible alternatives for implementing this scenario. They are depicted in Figure 39 and Figure 40.

In Alternative 1 (Figure 39), the PLC system is connected to a WLAN STA belonging to the ISP providing access to Internet. In this case there would be only one ISP. OPERA is used to provide access to the customers within the building. In the represented case the Head End is connected to a WLAN STA, though it could also have the wireless interface integrated into the HE itself.

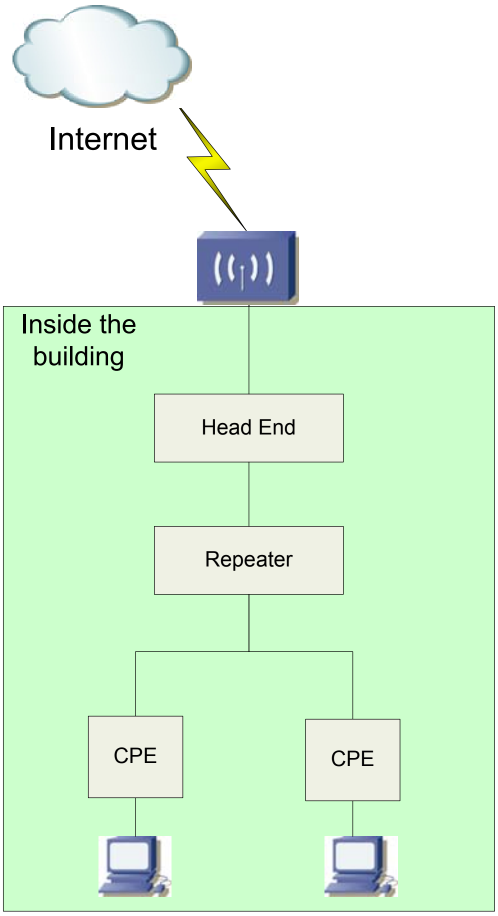


Figure 39. Alternative 1 of using WLAN to connect to the ISP.

In the second alternative (Figure 40) the HE is connected to a WLAN Access Point thus enabling several service providers to connect to the Head End through WLAN.

ISPs can connect to the PLC network in the Point of Presence (PoP) or directly through a WLAN STA. From the PoP, layer L2 networks distribute the information to the Head Ends. In the case of Figure 40 the L2 Network cannot reach the Head End and a WLAN connection is used. In chapter 6.2.2.1 a test case is proposed to test the configuration of alternative 2.

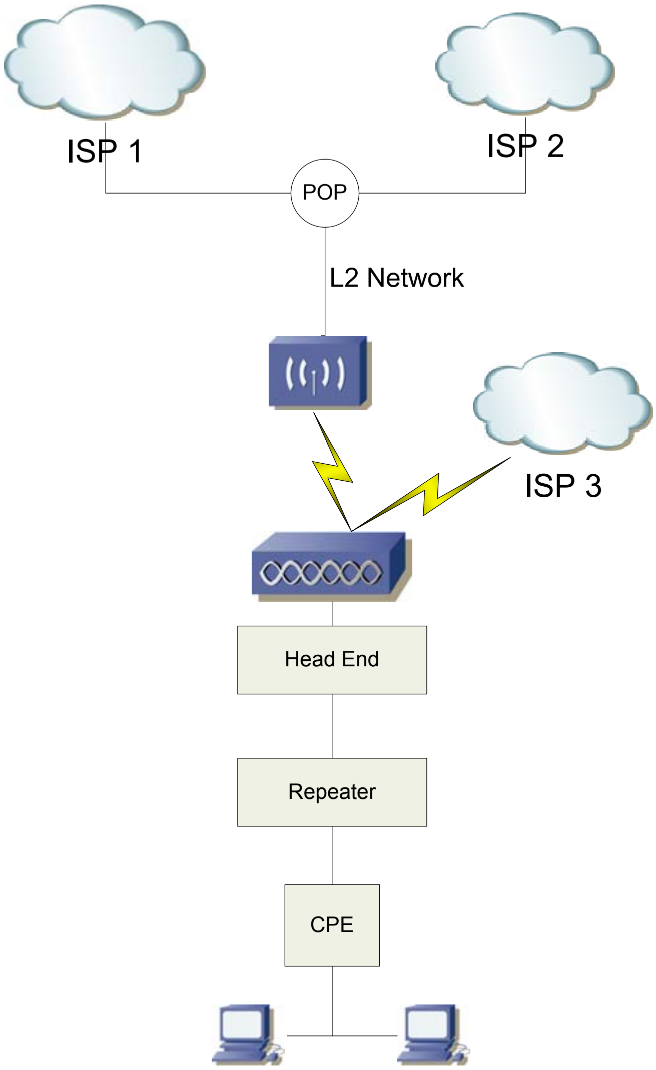


Figure 40. Alternative 2 of using WLAN to connect to the ISPs.

7.2.1.2 Scenario 2. WLAN interconnecting OPERA elements

The ability to interconnect two OPERA elements with WLAN instead of the usual electrical wire can have several useful applications. In these cases, the easiest thing to do is to encapsulate the OPERA data inside the 802.11 frames. From the point of view of the elements, the WLAN link acts just like another network segment. The difference is that the WLAN link does not follow physically the electrical network. Nevertheless this may be not a problem because the protocol supports segments where some elements cannot communicate with others (that is why repeaters exist).

WLAN can interconnect different elements of the PLC architecture:

2A. WLAN interconnecting the Head End and the repeaters. Represented in Figure 41.

2B. WLAN interconnecting Repeaters. Represented in Figure 42.

2C. WLAN Interconnecting Repeaters and CPEs.

In case 2A, the Head End and the Repeater are connected through a WLAN link. One application of this scenario could be having the HE separated from the electrical network, maybe in an outside nearby location.

Case 2B can be used to join two independent electrical segments of the network. If, for example, there is a user that wants access to the network and belongs to a LV segment of the network with no PLC service, it can be served by using only one repeater connected through Wi-Fi, avoiding the need for a new HE or more repeaters. This system can be deployed over MV and LV networks. It can also be used to extend to a LV segment a system deployed over a MV network.

Since for the case 2C, Wi-Fi interconnecting a Repeater and a CPE, it seems difficult to find practical applications, this possibility will not be dealt with anymore.

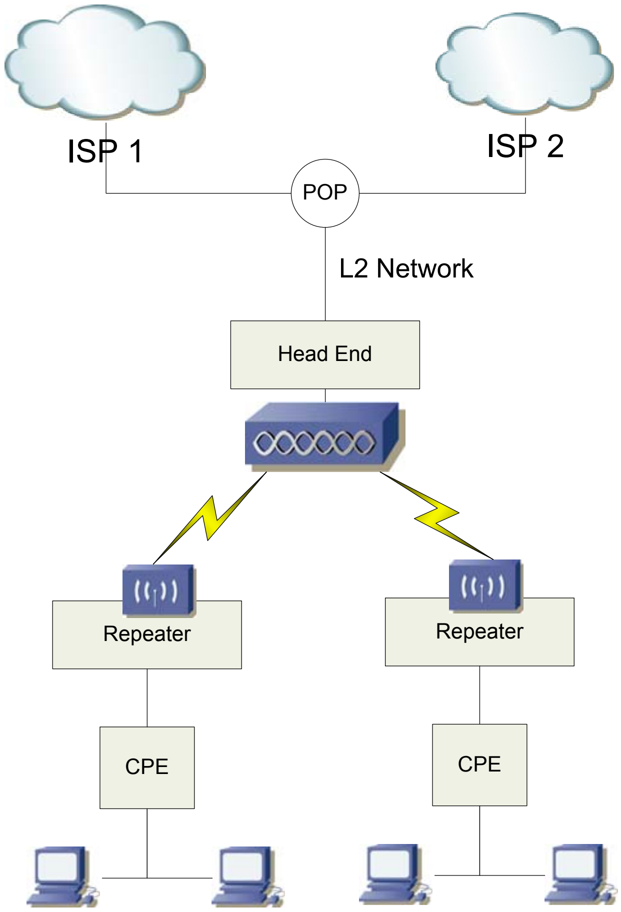


Figure 41. OPERA with WLAN interconnecting the HE and a repeater or a number of repeaters

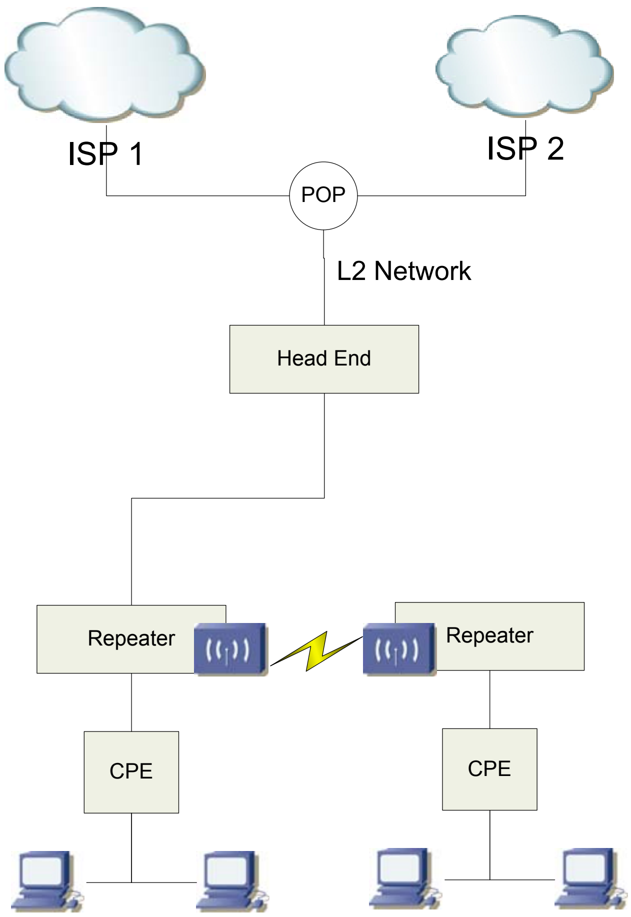


Figure 42. OPERA with a WLAN link interconnecting repeaters

7.2.1.3 Scenario 3. WLAN as a backup link in the network

In this scenario, shown in Figure 43, WLAN is used as a backup link of a PLC link. If a sudden loss of quality happens on the PLC link or if the link goes down, the WLAN link would serve as backup to solve the situation. In Figure 43 only one WLAN link has been represented, nevertheless the scenario is general and several WLAN links could exist even with point to multipoint architecture.

The WLAN link can be used strictly as backup so that the WLAN interface is only used when the link quality of the PLC link goes below a certain threshold. Of course a policy to use back the PLC link should be defined.

Another option is to share the load between the PLC and the WLAN link. This can be implemented by sending some of the bursts addressed to the other end through the WLAN interface and the rest through the power line.

In this latter case of load sharing between WLAN and PLC a simple load balancing sublayer has to be defined as indicated in Figure 44.

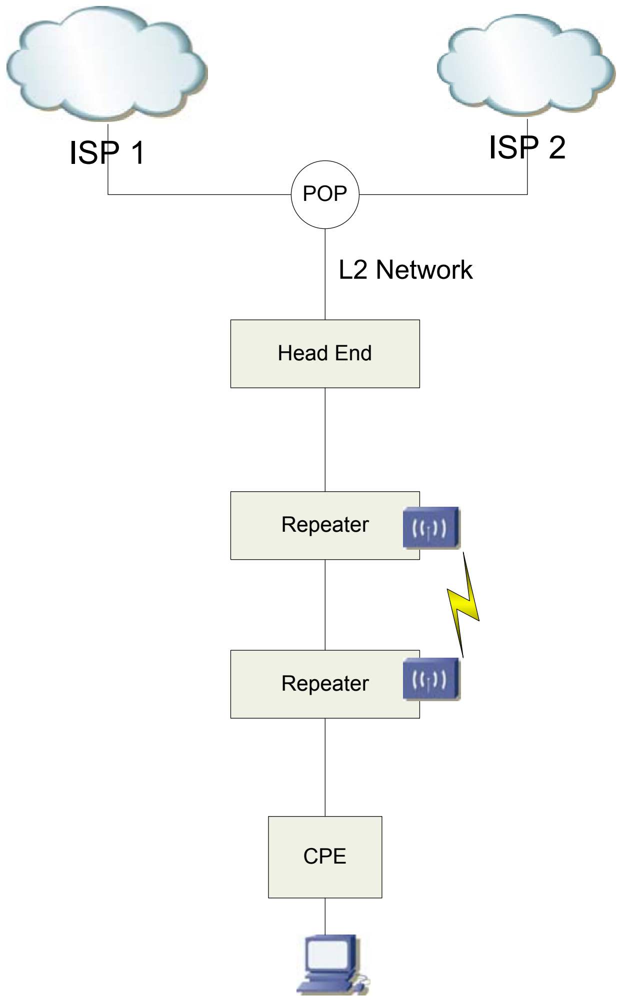


Figure 43. OPERA with WLAN as a backup link.

<table>
<tr><td colspan="2">Bridging</td></tr>
<tr><td colspan="2">Convergence</td></tr>
<tr><td colspan="2">LLC</td></tr>
<tr><td colspan="2">MAC OPERA</td></tr>
<tr><td colspan="2">Load balancing</td></tr>
<tr><td rowspan="2">Electric cable</td><td>802.11</td></tr>
<tr><td>Air</td></tr>
</table>

Figure 44. Load sharing between PLC and WLAN

7.2.1.4 Scenario 4. User access to OPERA via WLAN

In this case the connection between the CPE and the customer's device is via Wireless and Wi-Fi is completely coordinated with the PLC system and assumed to be controlled by the same provider. The architecture is similar to what is being done for DSL in many deployments. Having Wi-Fi integrated in the CPE gives more value to the PLC network by enabling laptops and handheld devices to move around while connected to the network. The fact that the user can connect through Wi-Fi also enables new services like the availability of a LAN to interconnect all of its devices and telephony over Wi-Fi.

There can be one access point per user, using it as an in-home LAN, or shared with more users. Depending on the case, the scenario has different characteristics.

This architecture might facilitate the Fixed Mobile Convergence (FMC) since it enables the use of multi-mode terminals able to seamlessly transition form PLC to WLAN and from WLAN to cellular. In the FMC architecture the same is done by the use of DSL. Of course DSL can be replaced by PLC without changing the basic FMC architecture. In the FMC architecture the protocol used is typically UMA/GAN seen in chapter 5, this architecture allows for the use of Wi-Fi but also Bluetooth. The same architecture can be used in the case of PLC.

Several sub-scenarios can be defined. Next these scenarios are defined and analyzed. Finally, the integration and QoS issues will be described.

7.2.1.4.1 Sub-scenario 4A. Access Point integrated in one CPE

This sub-scenario, represented in Figure 45, has a number of applications. Next some of them will be described.

<u>CPE in users' homes:</u>

The first is having one CPE per user and letting the user connect to the CPE and the PLC system through Wi-Fi. This is very convenient because the user needs no installation at all, just plugging-in the Wi-Fi enabled CPE and everything should just work.

CPE shared among users:

Another application is having the CPE in the street, outside of the building, maybe in a MV mast. In that case, each CPE can be used to serve several customers through Wi-Fi. With this method, it is also easy to extend the Wi-Fi network by using Wi-Fi repeaters/range extenders. The user would receive the signal at home with a Wi-Fi capable device.

Another use of this scenario is giving public Internet access in a specific place by putting a series of Wi-Fi hotspots along a LV or MV line.

In the case of one of the APs losing the PLC connection, other Wi-Fi hotspots can be used as a failover mechanism. For example, if there are interferences in the LV network, the connection can be redirected through other hotspots as some market products do. This variant can be deployed either in LV or MV lines.

PLC systems can be concatenated by linking the CPE of one system with the HE of the other system. This architecture may be useful for linking a PLC access system deployed over aerial MV lines with an in-home PLC system at home. WLAN would serve to bypass the MV/LV transformer and the physical obstacles for getting into a house. It just jumps in through the window.

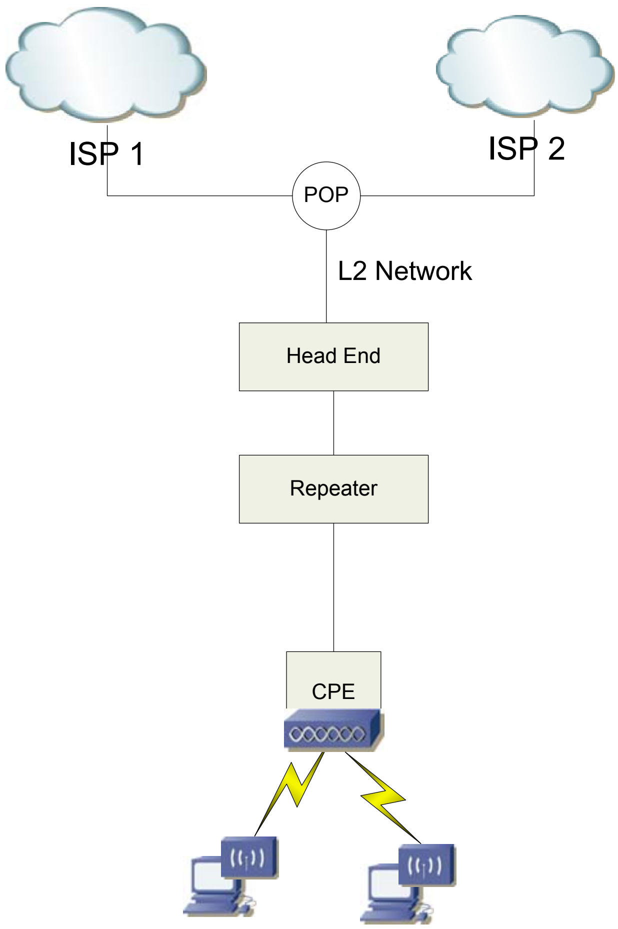


Figure 45. OPERA with WLAN in the CPE

7.2.1.4.2 Sub-scenario 4B. CPE in a LAN with access points

In this case WLAN is not integrated in the CPE. Rather than this, the access points are connected to the CPE through a LAN. The LAN can be any technology, from Ethernet to PLC.

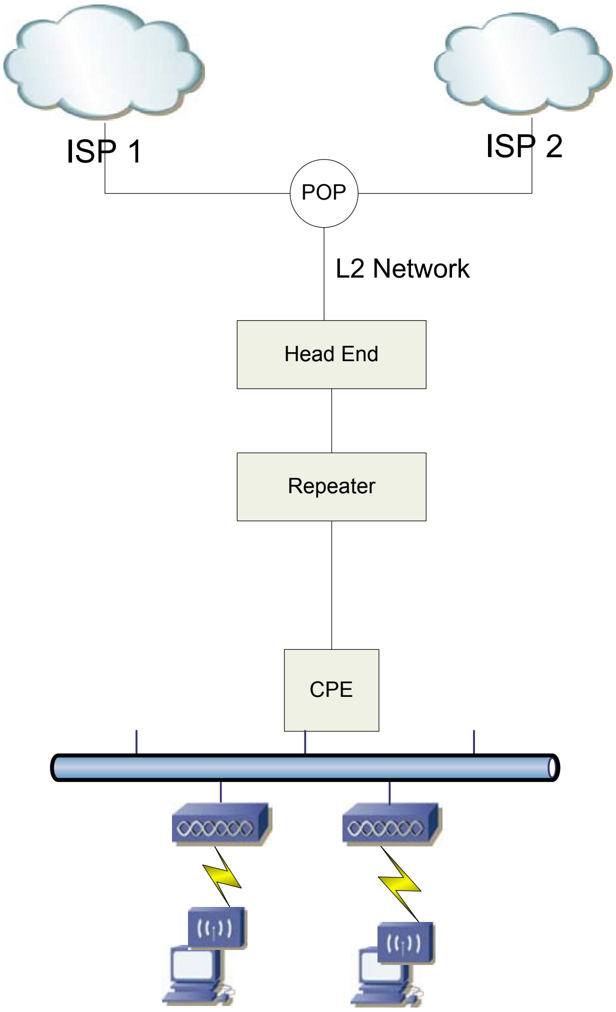


Figure 46. OPERA with Wi-Fi in a LAN

One use of this scenario is in a big house where one access point is not enough to cover the entire house. Here, several Access Points are connected between them through a LAN forming an ESS, and connected to the Internet through the CPE. In this case the LAN would act as the DS of the ESS. If the wired LAN is an in-home PLC it would be great because there would be no need for wires at all.

Apartment buildings with a wired LAN do not need a CPE per customer, just connecting the CPE to the LAN, and then every customer should have its own access point at home connected to the LAN.

7.2.1.4.3 Sub-scenario 4C. WLAN in several CPEs connected through OPERA

This sub-scenario looks similar to sub-scenario 4A but here there are several CPEs connected through OPERA, not just one. In this case OPERA is used as a LAN to create the DS of an ESS and this creates some specific situations.

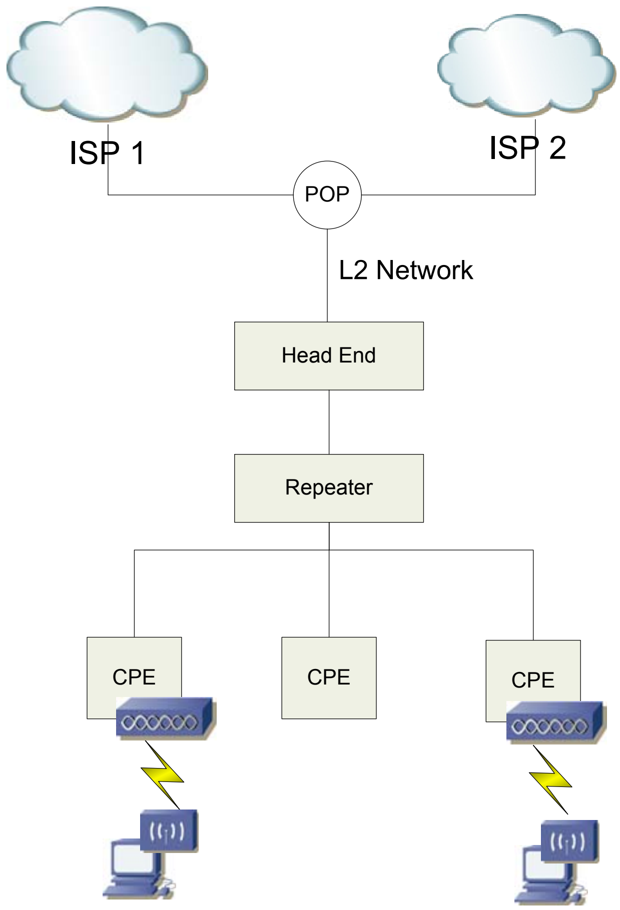


Figure 47. OPERA with WLAN in several CPEs

7.2.1.5 Scenario 5. Access to WLAN and PLC as independent networks

In this case the Wi-Fi network is connected to the Internet not through OPERA, but by other means (Figure 48).

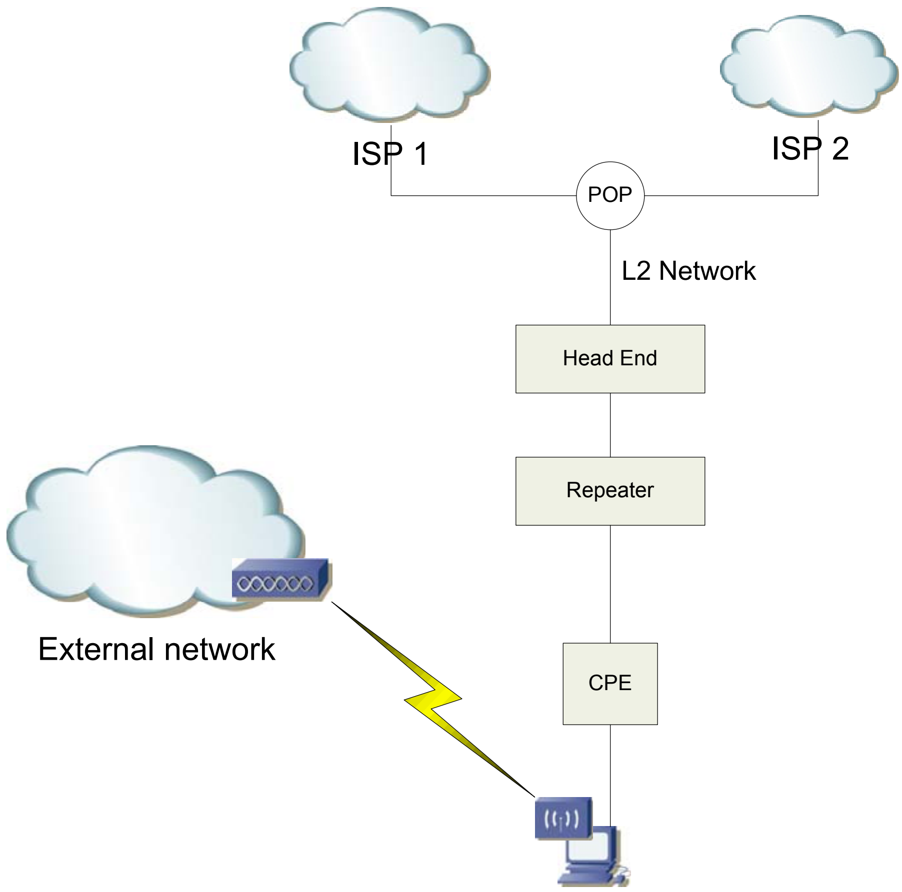


Figure 48. WLAN as an external independent network

7.2.1.5.1 Two separate networks

In this case the user has two options to connect to the Internet and other services, through the OPERA network or through Wi-Fi.

In this scenario the important part is the integration of networks and mobility. By integration we mean the ability of the devices to change from one network to the other and continue using the services, in this case PLC and Wi-Fi. In order to accomplish this, Mobile IP has to be supported. Optionally, to make handovers efficient and seamless, 802.21 can also be supported.

An example of use of mobility would be a user that is connected to the internet with a laptop attached to the PLC network. When the user disconnects the cable, the laptop would automatically connect to the Wi-Fi network and the user would be able to continue using the applications.

7.3 PLC + xDSL

When analyzing the possible integration scenarios using xDSL and Powerline, it is possible to say that these two technologies are flexible and scalable enough so that the integration between the two can be made using xDSL as backbone connection and Powerline as access to customers but also the other way i.e. Powerline as a backbone connection an xDSL as access.

The decision about the scenario to implement will depend on several factors and on planning decisions that the implementer will have to take.
For all the scenarios the implementation requirements and the advantages of such an implementation are presented.

7.3.1 Scenarios

PLC + xDSL

In this scenario the PLC is used as the backbone/distribution network and the xDSL is used inside the buildings for the access to the customers.

This scenario is suitable to high density areas with high vertical buildings where the PLC can have more difficulty to cover 100% of the building without having more than one stage repeater.

The use of a mini-DSLAM in building connected to the PLC repeater will allow serving all users with the same physical performances independently on if it is on the first floor or in the last.

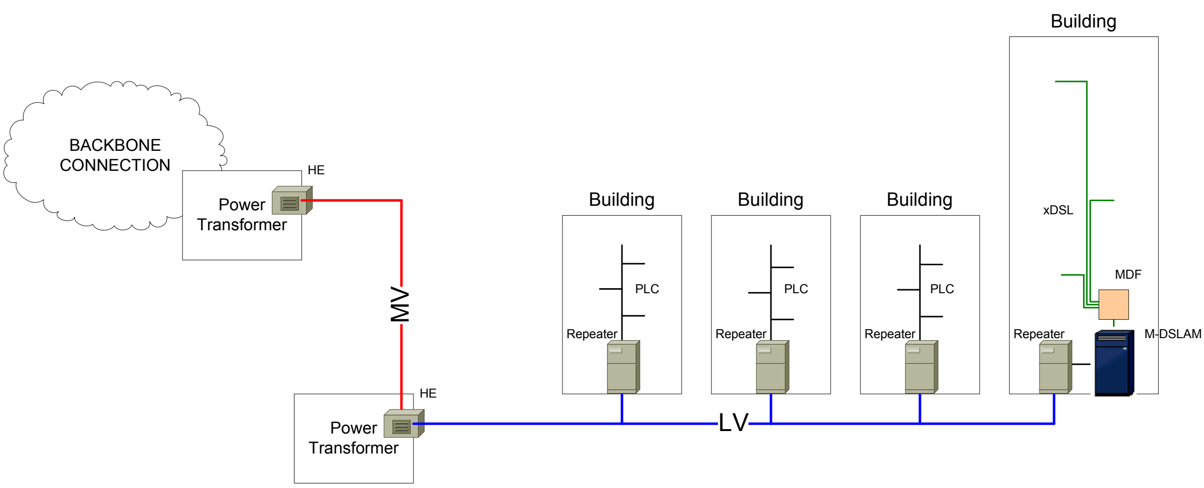


Figure 49. PLC + xDSL

Requirements to implement this scenario:

1. Buildings with copper cable infrastructure that belongs to the building.
2. Copper infrastructure terminated in a single point (MDF)
3. mini-DSLAM with Fast-Ethernet or Gigabit-Ethernet interface

This scenario has the following advantages:

1. high physical performances inside the building
2. less frequencies necessary for the PLC, better performances can be obtained with the optimization of the outdoor links
3. can cover high vertical buildings

xDSL + PLC

In this scenario the xDSL is used as the backbone/distribution network and the PLC is used as the last mile access (indoor and outdoor). For example, the xDSL can be installed in a central area (e.g. Sub-Station) and can distribute the backbone access by several Power Transformers allowing the creation of several cells in the area.

This scenario is suitable to overcome long Medium Voltage Links.

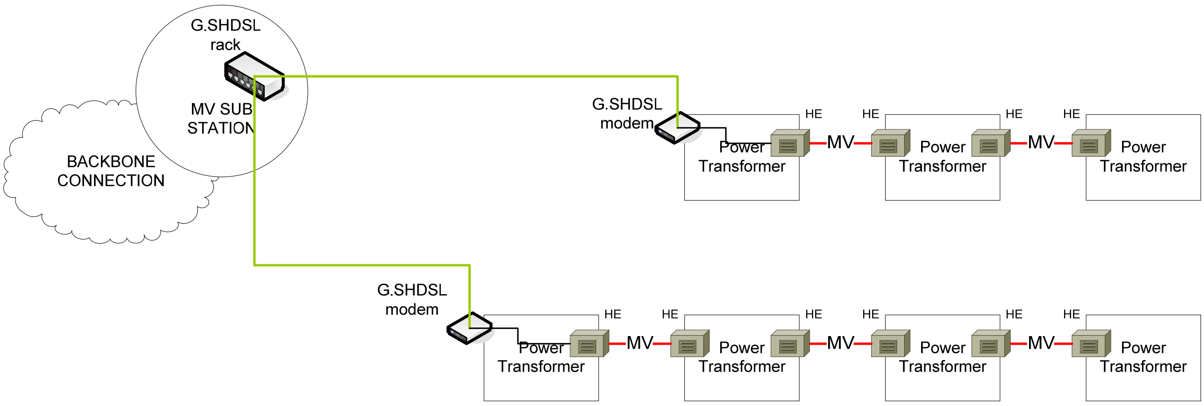


Figure 50. xDSL + PLC.

Requirements to implement this scenario:

1. Backbone connection present in a central area with Cooper infrastructure that reaches the Power Transformers
2. DSLAM (CO and CPE) with Fast-Ethernet or Gigabit-Ethernet interface

This scenario has the following advantages:

1. lower backbone implementation costs
2. solution to overcome long MV links
3. scalable bandwidth grow in the DSL links

xDSL + PLC + xDSL

This scenario is just a combination of the previous 2 solutions to show the flexibility of integration of these two technologies.

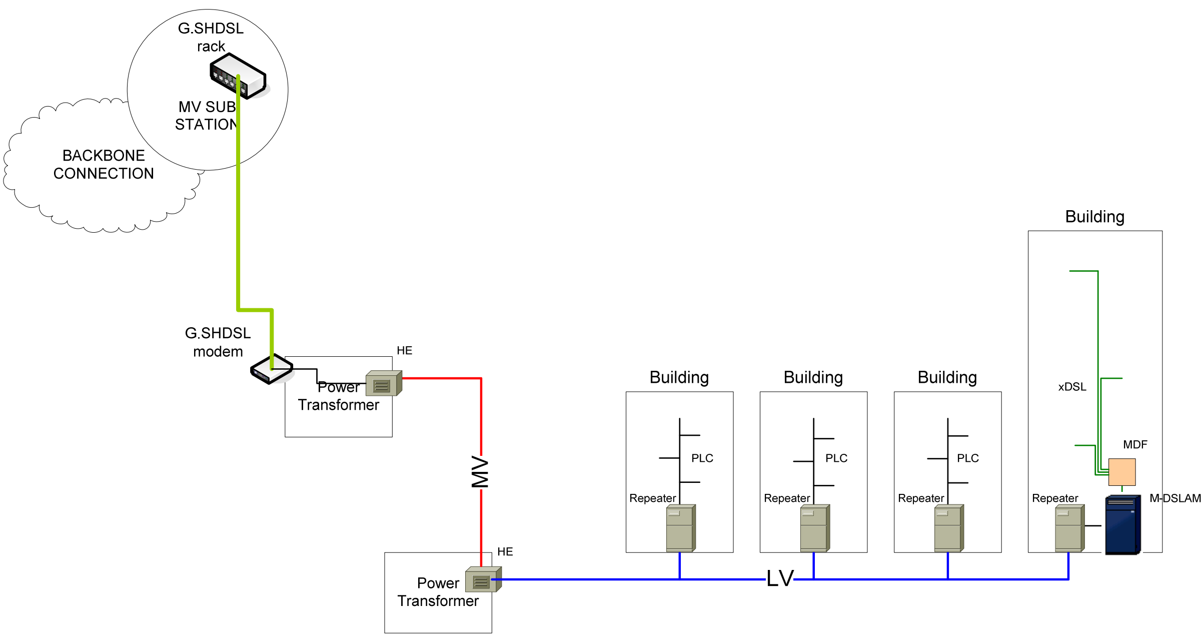


Figure 51. xDSL + PLC + xDSL.

7.4 PLC + Satellite

7.4.1 Scenarios

Satellite + PLC

The first scenario under analysis is shown in Figure 52. It uses a satellite connection as the backbone for Internet access, meanwhile the in-home distribution is made using PLC. This scenario appears to give Internet access to remote areas where a wired telecommunication infrastructure is not available. In the figure, only one house is shown, but other possibilities are also possible: for example, installation of a repeater in the rooftop of a building to deliver Internet access to different neighbours.

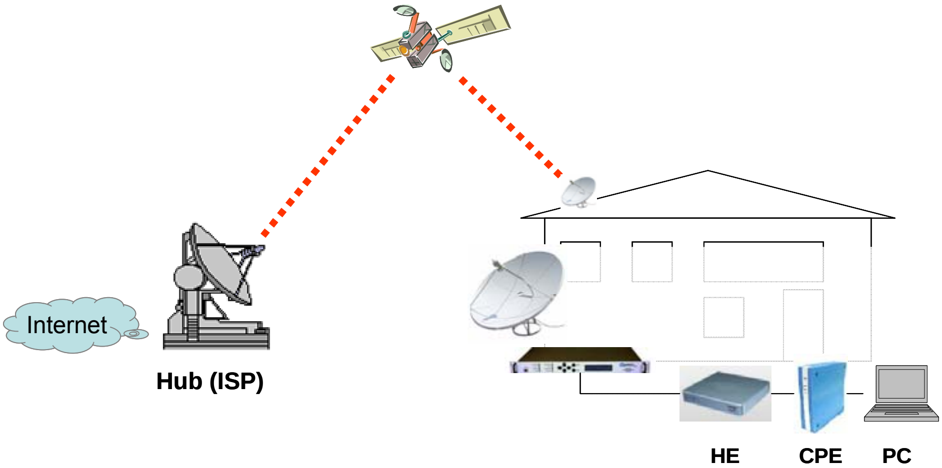


Figure 52. Scenario satellite (as backbone)+PLC (in-home).

The requirements to implement the scenario are:

1. Backbone connection via satellite using a VSAT station
2. HE and CPE to deliver in-home PLC (a repeater can also be necessary in case a large number of customers must be served)

Satellite + PLC + PLC

In this scenario, a satellite link is used as the backbone connection from a MV/LV station. The last mile and indoor distribution are provided using PLC. This scenario is typical in rural areas where the electrical power supply is provided by a substation, where the satellite station is installed. In case the substation supplies power to other MV or LV links, several PLC cells can be created.

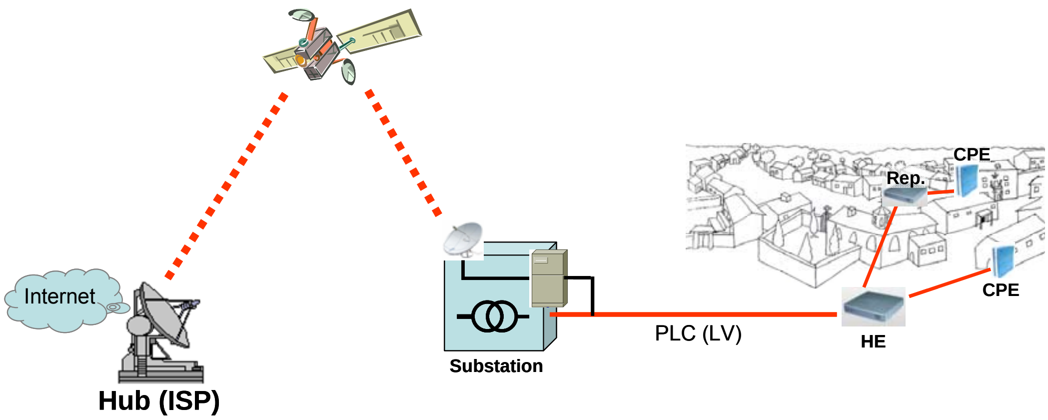


Figure 53. Scenario satellite (as backbone)+PLC (last mile and in-home).

The requirements to implement the second satellite+PLC+PLC scenario are:

1. Backbone connection via satellite in a substation
2. HE and CPE to deliver access and in-home PLC (a repeater can also be necessary in case the substation is far from the town location).

7.5 PLC + UMTS

7.5.1 Scenarios

Taking advantage of the current speeds provided by HSDPA devices (14.4 Mbps), it can be used as the backbone, in a scenario where the HSDPA card is connected to a repeater that distributes the signal inside the building using the PLC (Figure 54). In this scenario, several customers share the same HSDPA connection through the repeater. Other alternative would consist in that each customer would have its own HSDPA terminal and distribute the signal through a repeater inside the house.

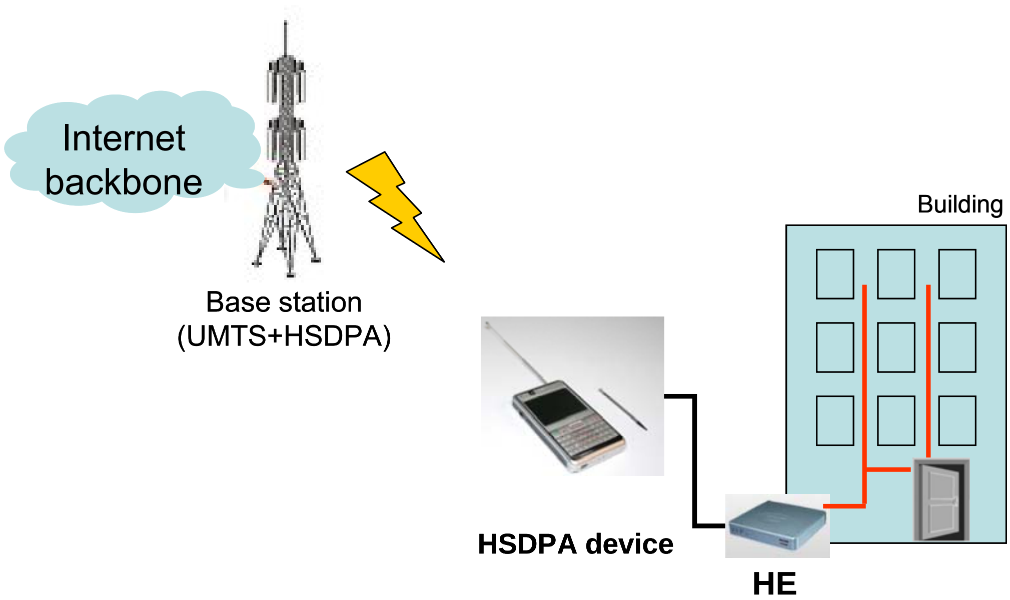


Figure 54. Scenario for PLC+UMTS (HSDPA).

8 Conclusions

In this report, a description of access technologies is presented, with special focus on the comparison of PLC with other wired and wireless technologies. The comparison is performed is terms of technical aspects (bit rate, range available, frequency) and system issues (deployment, standardization).

Starting with the deployment, PLC technology allows a rapid deployment and roll-out thanks to the use of existing infrastructure. In contrast to other access fixed technologies, such as FTTH and HFC, the deployment costs are significantly minor for PLC.

Regarding the range, PLC has lower than other fixed and wireless technologies. This makes the installation of repeaters mainly in LV lines a necessity. As an advantage, it is important to mention the ubiquity of PLC compared to others. In this sense, both PLC and satellite are the most appropriate technologies to provide services to remote access and rural areas, being the deployment of satellite networks more expensive.

In the area of capacity, technologies based on the use of fiber provided the larger bit rates. In case of PLC, the maximum capacity with the existing technology is 200 Mbps, that must be shared between the users. ADSL2+ and VDSL provide slightly higher capacities per user, with the weakness that the maximum capacity strongly depends on the distance to the station. The case of WiMax as wireless technology, providing a maximum of 70 Mbps per link, has the drawback of requiring Line-of-Sight conditions.

In case of symmetry, all wireless technologies except for satellite provide a symmetric service. Fixed technologies are mainly asymmetrical, meaning that the downlink rate is significantly higher than in the uplink, as it corresponds to most of multimedia services. Only PLC and FTTC provide the same capacity in the two links.

One of the main impairments of PLC compared to other technologies, namely the lack of standardization, is being solved these days.

Other differential feature of PLC is the variety of applications that can be provided to the utility. This is important also for the customer, as the safety, billing issues, comfort and consumption, are improved. This fact contributes to the improve the efficiency of the electrical power supply networks.

Finally, it is important to mention that PLC can also implement all the services based on its IP structure and functionalities that will foster the Broadband for All in Europe, including Teleworking, Tele-Surveillance, Telemedicine and e-Health, e-Learning and e-Government.

Also, it is important to say that PLC can be integrated with other access technologies to take advantage of the synergies and improve the QoS of the services. The aspects related to the implementation of an integrated network are covered in the Deliverable D13 “Reference guide on the design of an integrated PLC network, including the adaptations to allow the carriers' carrier model.”. The integrated PLC network will lead to the definition of new business models and cost analysis, that will be part of D33 “New business models and technical feasibility with WI-FI, WIMAX, UWB, ZigBee and Bluetooth”.

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