PALAS – Powerline as an Alternative Local AccesS
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Deliverable D5:
State of the Art and Initial Analysis of PLC Services
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Table of contents:

1 Aim and Focus

PowerLine Communication (PLC) has developed since the early 1920's and is today a technology on the threshold of being implemented for Information Society functions. This PALAS project report discusses the state of the art and gives an initial analysis of potential PLC-based service and application areas relevant to the Information Society.

A large potential application area is in telecom access services, where different applications have reached, or soon will reach, established markets of significant size. A growing field of applications is in the Internet data and content delivery sector, since the data transfer capabilities over the power lines have been increased substantially over the last few years.

PLC technology for large-scale in-home, office and building management services based on IP networks is another fast growing field, and the industry has already begun to adapt and develop components and systems for this market sector.

A promising future segment of PLC services relates to electronic power markets and e-business developments in the utility sector itself. Here, PLC technology plays an important role as an enabler of energy e-business and virtual enterprise. This is culturally very significant because this industry sector traditionally has had a regional rather than international focus. Deregulation and liberalization are further important drivers in this ongoing restructuring of the energy value chain.

This report gives an overview of all these areas.

Chapter 2 gives a historical introduction into early PLC applications. Chapter 3 presents a survey of the current PLC frequency standards and regulatory landscape, while Chapter 4 briefly outlines the recent PLC developments in the high frequency regime. Chapters 5–7 then discuss the various new PLC service areas at length, Chapter 5 focusing on baseline services, Chapter 6 on more advanced ones, and Chapter 7 on related service and operations cost issues and their dynamics. Chapter 8 indicates relevant ongoing work in European projects related to the PALAS project. Finally, Chapter 9 presents an outlook on how PLC may impact the energy value chain and the development of e-business in the utility sector. Chapter 10 gives an executive summary of the main findings.

This report focuses on applications and services rather than on technology, which is reported in other PALAS deliverables. Most of the report covers what may be seen as services for the Information Society, and how the electrical grid will serve as an access and delivery network for those kind of services.

This first report lays a foundation for upcoming work focused on a framework for the development of new services, and on field trials assessing how the PLC service potential can be practically realized. It is our sincere hope that this report will provide the reader with a good understanding of the present state of PLC, and support business executives in framing the key questions, issues and answers in how to exploit PLC applications and services.

2 Early Applications of PowerLine Communication

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2.1 Birth of PLC

The idea behind using power lines as a medium for delivering more than just electric power dates back to the early 1920's. In those early days, high voltage cables were considered to be a possible alternative to installing expensive pilot wires, especially in remote areas where distances of a few hundred kilometres were not uncommon [1] [2] . The need for remote network monitoring and control may have been the driving force, but even then, voice circuits were under consideration.

With only a few exceptions, signalling on power lines was restricted to networks of greater than 11 kV, where lines tended to run point to point between substations. At 11 kV and below, spur lines and transformers caused high signal attenuation.

Traditionally, frequencies below 150 kHz have been used. This was eventually formalised in the CENELEC bands for power line communications outlined in EN50065-1. Radiated signal strength has always been considered a problem and therefore frequencies were chosen so as not to interfere with services such as aircraft navigational aids, broadcast radio and open-wire telephone systems. Services only requiring a very short time slot at long intervals such as carrier-feeder protection were allowed to use power levels and frequencies that could not be tolerated for speech and telemetering systems.

By the 1950's low frequency power line technology was widely used on high voltage networks for the transmission of Supervisory Control, Remote-Indication, signalling associated with protective and intertripping equipment, and the transmission of speech. Power line coupling equipment was large and expensive; the decision to install a power line solution instead of pilot wires was based on cost. As a result, power line techniques were mainly utilised in remote areas where alternatives were not available, making PLC cost effective.

The cost of high voltage coupling equipment came from the fact that it was installed either in series or parallel with the high voltage circuits. In-series line choke coils had to carry the power line load and have the ability to withstand currents under fault conditions; coupling capacitors had to withstand line voltages.

Both phase-to-phase and phase-to-earth transmission techniques were available, and once again the cost of each was an important factor. However, for those companies who could afford it, phase-to-phase transmission was the preferred solution for the following reasons:

- Signal attenuation was reduced and consistent.
- A much better signal to noise ratio was achieved.
- Variations in signal attenuation due to weather conditions are greater when using phase-to earth techniques.

- On a phase-to-earth system, a fault on the phase conductor could result in the loss of signal. With phase-to-phase coupling the loss of one of the phase conductors results in only a slight increase in signal attenuation.
- Radiated signal from a phase-to-phase system is much smaller than that for a phase-to-earth system.

The cost of phase-to-phase transmission was greater due to the fact that twice as much high voltage coupling equipment was required.

The networks discussed so far have been high voltage overhead networks with few, if any, discontinuities. These networks provided the most stable environments for PowerLine Communications. However, noise interference had also to be taken into consideration. The main interference source came from corona and arcing which resulted in wide-band noise reducing the signal to noise ratio. The situation was made worse by bad weather. Nevertheless, even in adverse conditions acceptable signal to noise ratios were available over sections of high voltage network in the order of 185 km in length. Another source of noise came from switching and isolation operations, which produced wide-band noise and surges of considerable amplitude. Their short duration however meant that their adverse effects were short lived.

One of the exceptions to the greater than 11 kV rule, and one power line technology that has enjoyed modest success, was the development of Ripple Control, which superimposed audio frequency (AF) tones onto the low voltage power signal in order to transmit simple 'on'/'off' instructions [3] [4] [5] . Ripple Control was first investigated by the power board of Davos, Switzerland, in 1929. The mains frequency was modulated with a burst of AF signal, each burst lasting for the duration of several mains frequency cycles. A number of these AF bursts were joined together to form a signal code which could be received and deciphered at various points throughout the network. The system was used to switch on and off, large numbers of similar units such as streetlights, water heaters, shop illuminations and multi-tariff meters.

Different audio frequencies were used for different applications allowing a number of services on the same system. Tuned circuits in the receiver equipment detected only signals relevant to its operation. Ripple Control equipment was still being manufactured by Landis and Gyr in the late 1960's.

Modulating the mains signal with AF signals required equipment that was large, costly, and required regular maintenance. In the late 1950's a system offering economic attractions and minimal size and maintenance requirements was devised. Peak Depression arranged discreet marking of selected cycles of the 50/60 Hz mains, rather than modulating the mains with a unique signal frequency. Marking was achieved by applying a limited and precisely controlled short circuit. The short circuit drew heavy current for a few microseconds at a precise pre-selected position on the voltage wave. The pulse current, 200 to 300 A, had a sharp leading edge and saw the system as a high impedance with excellent propagation characteristics. A series of pulses was arranged to form the telegram. A complete telegram comprised 3 impulses discretely placed within a 16-cycle period of the 50/60 Hz supply. As Peak Depression signalling developed, it was determined that restricting the modulation to a small area around voltage zero prevented disturbance/interference to sensitive loads connected to the mains, for example lighting and television. It also reduced signal attenuation to a minimum, allowing signals to be correctly received throughout the network. This technique, known as Cyclocontrol, increased the complexity of the coding in order to allow addressing. In 34 mains supply cycles, 165 discreet addresses were available with four possible instructions.

Ripple Control and its successors have been used on networks around Europe for many years, and although somewhat dated, operational examples can still be found today.

In 1936 Bell Telephone Laboratories began investigating the possibility of using power lines as a means of providing a telephone service to rural customers in sparsely settled areas of the United States [6] . Initial investigations using voice frequencies proved impracticable due to the high transmitting power required to overcome ambient noise levels. Efforts were therefore focused on high frequency techniques where power line noise levels were less of a problem. The frequencies used were between 150 kHz and 455 kHz. At frequencies below 150 kHz coupling problems became increasingly difficult, and at frequencies above 455 kHz high line attenuation and interference from broadcasting stations limited the usefulness of the system.

The system was designed to work on the typical US rural distribution network, made up of a single-phase pole mounted conductor, operating at 7 kV and 60 Hz, with a lower neutral wire that was grounded at frequent intervals. The system could work on networks that were up to 20 miles (32 km) in length. Due to the large number of taps and branches associated with a distribution network, a series of in-line isolating and transmission chokes were required in order to reduce signal attenuation to a minimum.

The project was abandoned in 1941 with the entry of the USA into the Second World War, but reinstated in 1945. By October 1946 the Bell team had developed a power line telephone system known as the M1 Carrier Telephone System which was manufactured by the Western Electric Company.

2.2 The last thirty years

Over the last thirty years development work has concentrated primarily on automatic distribution functions such as automatic meter reading, selective load control and demand-side management. All of this work has fallen within the CENELEC band of frequencies and has been led by university and utility based research projects. The overall desire has been to develop a system capable of helping the utility change the shape of its demand curve. By levelling out the twenty four hour demand curve electricity producers can reduce the cost of production. Peaky demand such as at meal times requires the use of plant that is quick to come on line but expensive to run; examples of this type of plant would be gas fired power stations. If the demand for electricity could be made more even and spread throughout the entire twenty four hour period, cheaper generating plant could be better utilised, the overall cost of implementing such a system being justified by the savings in production costs. On the back of this network management system, other services could be operated that financially could not be justified on their own such as automatic meter reading and network monitoring. Almost without exception, these projects have led to a better understanding of power line characteristics and issues, but they have not resulted in widely available products and services. The following examples are representative of the type of project work undertaken by utilities up until the early 1990s.

The Wisconsin Electric Power Company in the US investigated the possibility of using power line carrier over its distribution lines in order to implement a load management system in the mid 1970’s [7] . The system was designed for the remote reading of electricity, water and gas meters equipped with suitable digitising encoders. Loads such as water heaters and central air conditioners could also be controlled via auxiliary switching units. A domestic transponder could service up to four switchable loads and three different meters. For one of the meters, registers were available for implementing ‘time of day’ metering with a rate structure of two or three periods and memory of peak demand for a selected period.

The Credit And Load Management System (CALMS) was developed by the South Eastern Electricity Board in the UK in the early 1980’s [8] . Based around an ‘intelligent’ home terminal and using a number of different communication media, CALMS was not dependent upon PowerLine Communications alone. The system was designed to give more accurate information to both the customer and the utility, enabling the utility to make better use of its resources and the customer to monitor the cost of electricity and tailor his or her usage to benefit from multi-rate tariffs offering cheaper electricity at various times of day. The services offered were as follows:

- Measurement and recording of demand and maximum demand.
- Remotely selectable tariffs.
- Calculation of outstanding charges for continuous display to the customer.
- Provide electrical loading and demand information to assist in the network planning and control.
- Ability to institute tariff and price revisions remotely.
- Remote reading of a 3-rate meter.
- Accept customer payments remotely.
- Apply load limits for use in tariffs or in system emergencies as an alternative to rota disconnection.
- Remote reading of gas and water meters.
- Earth leakage protection facilities at customer’s premises.

In the mid 1980’s, a UK consortium made up of representatives of the electricity, gas and water industries, THORN EMI, and supported throughout by the Department of Trade and Industry, the Department of Energy and Ewbank Preece Consulting Ltd, ran field trials on a mainsborne telecontrol system [9] . THORN EMI was commissioned to design and manufacture microprocessor based equipment for the 1000 user trials, and opted for using a form of spread spectrum signalling to overcome the problems of noise on the low voltage distribution network. Up until this time, spread spectrum signalling had been used almost exclusively for military communications.

The trial system offered the following functions:

- Multi-tariff registers for each of the electricity, gas and water meters.

- Two contactors of 25 A and 80 A switching capability for control of water and space heating loads.
- 24 hour, half hourly consumption registers for analysis of load pattern variation.
- Display of time, consumption of electricity, gas and water, cost and quarterly bill prediction.
- Provision of override facilities for the customer to control water and space heating loads.
- Tamper detection.

The conclusions of the trials working group was positive and listed a number of reasons for continuing the development of a mainsborne telecontrol system.

In the late 1980's, Italy's largest electricity utility, ENEL, set down the specifications for a trial on their network [10] . The purpose of the trial was to demonstrate the feasibility of using the low voltage network as a data transmission medium. Three companies from the IRI-STET group were employed to develop and investigate the technology: Esacontrol, Italtel-SIT and SGS Microeletronica. The driving force behind the project was the desire to optimise the use of resources available for generating electrical power and to control user consumption. The system was designed to provide the following services:

- Frequent remote reading of consumption data for connected users.
- Daily updating of different charge bands.
- Power consumed by individual users limited to a contractual value.
- Peak power delivered during a one-month period recorded.
- Power consumed by all connected users limited to help resolve critical conditions of availability.
- Power delivered by substation and the sum of the powers delivered to individual users compared to evaluate network losses.
- Notification of any attempt to tamper with supply.

Datawatt's Robcom system was developed in The Netherlands in the late 1980's and early 1990's [11] . The system was tested in The Netherlands and Switzerland. Robcom used frequency hopping spread spectrum and covered both the medium voltage and low voltage networks. The system was designed to support Distribution Automation on the medium voltage network and Load Management on the low voltage network. On the medium voltage network the following services were offered:

- Monitoring of energy flows at various points along the network.
- Fault location.
- Continuous measurement and control of voltage levels throughout the network.

On the low voltage network the following services were offered:

- Tariff switching.
- Load shedding.
- Load cycling.
- Remote meter reading.
- Fault location.

In the late 1980's in the UK, NORWEB (one of the UK's twelve electricity utilities), in association with the Open University, started to investigate PowerLine Communications. The initial phase of the project started in much the same way as those already discussed, with an investigation into services such as load management and remote meter reading. The project team quickly came to the conclusion that these services, on their own, could not generate enough revenue to justify a utility investing the huge sums of money required to install the infrastructure necessary for a utility-wide service. It was obvious to the team that in order for PowerLine Communications to be successful, it had to offer services that utility customers would want to buy. Services such as voice and data transfer were considered, but the data rates available in the CENELEC bands were not high enough. For the first time, NORWEB started to investigate the possibility of using frequencies greater than 1 MHz on the low voltage distribution network. Early successes led to a telephone demonstration network in Manchester, England, based on CT2 technology. NORTEL Networks produced the telecom equipment. United Utilities, NORWEB's parent company, joined forces with NORTEL Networks in 1998 to create NOR.WEB DPL Ltd. NOR.WEB DPL was set up to develop and market a high speed Internet service using frequencies greater than 1 MHz on the distribution network. Pilot projects were undertaken in a number of countries. Although the company proved the principle of using high frequencies on electricity distribution networks, NOR.WEB DPL Ltd closed down in September of 1999.

2.3 Chapter references

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3 Frequency Band Standards and their Extension

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CENELEC, the European Committee for Electrotechnical Standardization, is a non-profit-making technical organization set up under Belgian law and composed of the National Electro-technical Committees of 19 European countries.

A European Council Resolution of 7th May 1985 formally endorsed the principle of reference to European standards within the relevant European regulatory work (i.e. Directives), thereby paving the way to a New Approach in the philosophy of regulations and standards in Europe. Under this New Approach, CENELEC is preparing a coherent set of voluntary electro-technical standards to further the Single European Market/European Economic Area without internal frontiers for electrical and electronic goods and services inside Europe. It also seeks to co-ordinate voluntary certification and testing schemes for electro-technology [1] .

The focus of CENELEC and the frequencies that were agreed and allocated for PowerLine Communications by them have been ideal for the purpose for which they were intended, i.e. telemetry within the power distribution industry. Employing these frequencies for use in a commercial telecommunications network present physical barriers in terms of achievable bandwidth which render the prospect of a commercial telecommunications access system on the PowerLine platform, at these frequencies, impractical. Currently there are no frequencies allocated by CENELEC above 148.5kHz.

The current CENELEC standards applying to this frequency band are as follows:

<u>STANDARD REFERENCE:</u>
EN 50065-1:1991

<u>TITLE:</u> Signalling on low-voltage electrical installations in the frequency range 3kHz to148.5kHz
– Part 1: General requirements, frequency bands and electromagnetic disturbances.

<u>CLC/TC:</u>
CLC/SC 205A

<u>TECHNICAL BODY:</u>
CLC/BTTF (BTWG)

<u>IEC/TC:</u>
IEC/TC & JTC1/25

<u>DIRECTIVES:</u>
89/336/EEC;73/23/EEC

<u>SCOPE:</u>

This standard applies to electrical equipment using signals in the frequency range 3 kHz to 148,5 kHz to transmit information on low voltage electrical systems, either on the public supply system or within installations in consumers' premises. It specifies the frequency bands allocated to the different applications, limits for the terminal output voltage in the operating band and limits for conducted and radiated disturbance. It also gives the methods of measurement. It does not specify the signal modulation methods nor the coding methods nor functional features (except those for the prevention of mutual interference). Environmental requirements and tests are not included. Note that in most countries the transmission of information is subject to regulation. Compliance with this standard does not imply permission to establish communication with locations outside the consumer's installation or with other consumers through the public supply system where this would not otherwise be allowed.

AMENDED AS FOLLOWS:
Reference: EN 50065 – 1:1991/A1:1992
Title: Amendment to clause 4,6 & 7 and annex C of EN
Directive: 89/336/EEC
CLC/TC: CLC/SC 205A

Reference: EN50065 – 1:1991/A2:1995
Title: Amendment to clause 7 and addition of annex E
Directive: 89/336/EEC
CLC/TC: CLC.SC 205A

Reference: EN50065 – 1:1991/A3:1996
Title: Amendment to clause 6 & 9 and subclause 8.1and addition of annex E
Directive: 89/336/EEC;73/23/EEC
CLC/TC: CLC.SC 205A

The allocation of higher frequencies brings along issues relating to radiation that initially are contained within permissible radiation standards defined by CISPR. Eventually, if practical systems cannot adhere to the CISPR standard, this will require the allocation of designated frequency bands which invokes a complex and lengthy process of national and ultimately international radio spectrum allocation issues. This encroachment of the allocated radio spectrum by high frequency, high power, PLC, imposes severe regulatory barriers to the commercial deployment of PowerLine access technology.

The CENELEC standard was outlined in EN50065-1 and was set in 1991. The band from 3kHz to 148.5kHz was split into sub bands with each band being allocated to different users.

3.1 CENELEC standard frequency bands

The following frequency bands are designated by the CENELEC standard EN50065:

The frequency range 40 kHz to 90 kHz is designated as Band A and is for electricity supply industry use only. Frequency range 110 kHz to 125 kHz is designated as Band B and is for mains signaling equipment needing continuously available channels; may be used to send occasional signals. Frequency range 125 kHz to 140 kHz is designated as Band C and is for mains signaling equipment which does not send out signals continuously, i.e. time shared or burst mode. Frequency range 40 kHz to 90 kHz is designated as Band D and is for mains signaling equipment restricted to consumers' premises where: (a) the consumer takes the supply at high voltage; or (b) an agreement is reached between the consumer and the supply authority. Frequency range 140 kHz to 150 kHz is designated as Band E and is for fire and security equipment. Frequency range 3 kHz to 8.5 kHz is designated as Band F and is for mains signaling equipment needing continuously available channels; it may be used to send occasional signals.

Modulation is, by definition, the process of changing the characteristics of a carrier wave by some predefined modulating function. In Phase Shift Keying the characteristic that is changed is the phase of the original carrier. This change in phase is limited to predetermined discrete values.

In BPSK (Bi Phase Shift Keying) modulation, two defined phases allowed, each phase shift transmits one bit of information. That is to say, if a receiver decodes a signal and this signal is “in phase” with a reference signal, the digital value can be defined to be a logic 0; if the received signal is “out of phase” with the reference signal this can be assigned to be a logic 1.

In QPSK (Quadrature Phase Shift Keying) modulation, four defined phases allowed, each phase change transmits two bits of information. For example, if a received signal is in phase with a reference signal then this can be defined to be logic bits 00, a phase shift between the received signal and reference signal of $\pi/2$ can be defined to be logic bits 01, a phase shift of π can be 10 and a phase shift of $3\pi/2$ can be 11.

From the two examples given it can be seen that though the occupied bandwidth is the same in both cases, the second example, QPSK, can transmit twice as much information as the first example. If both phase and amplitude are varied, QAM (Quadrature Amplitude Modulation), then the number of bits transmitted per Hertz of bandwidth can be increased further. With current communications it is common to find QAM 32 and QAM 64 where 32 and 64 discrete variations of phase and amplitude are permitted for each received time slot.

A normal analogue telephone line is assigned a frequency spectrum from 300Hz to 3.4kHz, a bandwidth of just over 3kHz. Current modem technology for these lines can offer data rates of 56 kbits/sec download and 28.8 kbits/sec upload. This equates to 19 bits/Hz download and just under 10 bits/Hz upload.

Because of the hostile nature of the channel on power distribution networks the more complex modulation techniques will fail. It may be reasonable to assume that the communication channel will support similar technology to the dial up modems available for analogue lines. Applying this type of technology to the CENELEC bands would give maximum data rates as follows:

Band A - approximately 1Mb/sec downstream and 480kb/sec upstream
Band B - approximately 285kb/sec downstream and 144kb/sec upstream
Band C - approximately 285kb/sec downstream and 144kb/sec upstream

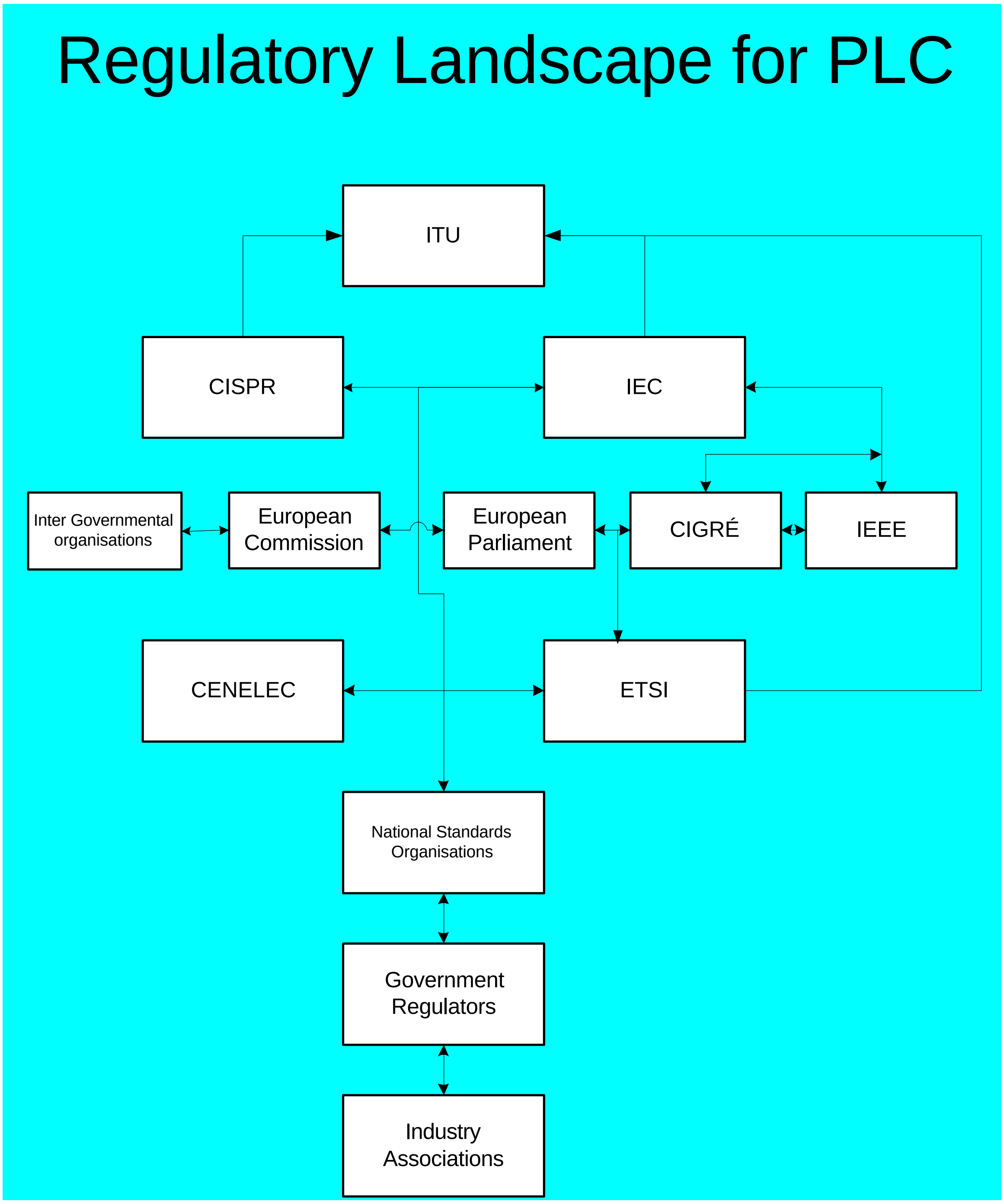
Band E - approximately 190kb/sec downstream and 96kb/sec upstream
Band F - approximately 104kb/sec downstream and 53kb/sec upstream

NOTE: Bands B & C can only used for burst mode transmissions so the data rates given cannot be achieved all the time.

The figures given are the absolute maximum that could be achieved using existing technology. This means that with bands A, B & F summed together and applied to access, the maximum data rate that could be achieved on the wires would be 1.5Mbit/sec downstream and just under 700kbit/sec upstream. These data rates would need to be multiplexed between all users of the low voltage network. This could be as many as 700 users. Clearly this system would not meet current expectations for a viable access solution.

3.2 The regulatory landscape for PLC

CENELEC is part of a complex advisory and regulatory network landscape and protocol through which standards and the allocation of the radio spectrum is derived. The following diagram and notes are intended to provide an overview of the approximate relationship between the various key players.



<u>ETSI</u>

ETSI (the European Telecommunications Standards Institute) is a non-profit organization whose mission is to produce the telecommunications standards that will be used for decades to come throughout Europe and beyond. Based in Sophia Antipolis (France), ETSI unites 773 members from 52 countries inside and outside Europe, and represents administrations, network operators, manufacturers, service providers, research bodies and users. Any European organization proving an interest in promoting European telecommunications standards has the right to represent that interest in ETSI and thus to directly influence the standards making process.

ETSI's approach to standards making is innovative and dynamic. It is ETSI members that fix the standards work programme in function of market needs.

Accordingly, ETSI produces voluntary standards - some of these may go on to be adopted by the EC as the technical base for Directives or Regulations - but the fact that the voluntary standards are requested by those who subsequently implement them, means that the standards remain practical rather than abstract.

ETSI promotes the world-wide standardization process whenever possible. Its Work Programme is based on, and co-ordinated with, the activities of international standardization bodies, mainly the ITU-T and the ITU-R.

ETSI consists of a General Assembly, a Board, a Technical Organization and a Secretariat. The Technical Organization produces and approves technical standards. It encompasses ETSI Projects (EPs), Technical Committees (TCs) and Special Committees [2] .

<u>IEC</u>
The International Electrotechnical Commission (IEC) is the international standards and conformity assessment body for all fields of electrotechnology.

Founded in 1906, the International Electrotechnical Commission (IEC) is the world organization that prepares and publishes international standards for all electrical, electronic and related technologies. The IEC was founded as a result of a resolution passed at the International Electrical Congress held in St. Louis (USA) in 1904. The membership consists of more than 50 participating countries, including all the world's major trading nations and a growing number of industrialising countries.

There are two forms of active participation in the IEC's work. Full membership gives countries the possibility of fully participating in international standardization activities. Full members are National Committees each having equal voting rights. Associate membership allows for limited participation of countries with limited resources. Associate members have observer status and can participate in all IEC meetings. They have no voting rights [3] .

<u>ITU</u>
The International Telecommunication Union (ITU), headquartered in Geneva, Switzerland is an international organization within which governments and the private sector coordinate global telecom networks and services [4] .

<u>CIGRE</u>
CIGRE (International Conference on Large High Voltage Electric Systems) is a permanent non-governmental and non profit-making International Association based in France [5] . It was founded in 1921 and aims to :

- Facilitate and develop the exchange of engineering knowledge and information, between engineering personnel and technical specialists in all countries as regards generation and high voltage transmission of electricity.
- Add value to the knowledge and information exchanged by synthesizing state-of-the-art and world practices.
- Make managers, decision-makers and regulators aware of the synthesis of CIGRE's work, in the area of electric power.

More specifically, issues related to the planning and operation of power systems, as well as the design, construction, maintenance and disposal of HV equipment and plants are at the core of CIGRE's mission. Problems related to protection of electrical systems, to telecontrol and telecommunication equipment, are also part of CIGRE's area of concern.

CIGRE shall be recognised as the leading worldwide Organization on Electric Power Systems, covering their technical, economic, environmental, organisational and regulatory aspects.

Technical work is being carried out within 15 Study Committees. The task of these Committees is to initiate and coordinate studies contributing to technical advance in their particular area.

Moreover, they must take part in the organisation of Plenary Sessions and select the Preferential Subjects to be discussed during these sessions. Membership of these Study Committees (which include 24 members each) consists of well-known experts, who are nominated by the Governing Bodies of CIGRE for a period of 6 years. Their term of office may be renewed for two-year periods if need be. Working Groups which include other experts are formed whose task is to delve further into a particular topic.

Governing bodies consist of:
The Administrative Council - 52 members with decision-making power.

The Executive Committee - 13 members, an advisory body making recommendations to the Council.

The Technical Committee comprising the Chairmen of the 15 Study Committees. This body is responsible for the technical direction and work of the Association.

CIGRE is represented through a National Committee in 52 countries. These National Committees play an important role locally as intermediary between members and the Central Office for all administrative processes related to the running of the organisation.

<u>IEEE</u>
The IEEE is a non-profit, technical professional association of more than 350,000 individual members in 150 countries [6] .

Through its members, the IEEE is a leading authority in technical areas ranging from computer engineering, biomedical technology and telecommunications, to electric power, aerospace and consumer electronics, among others.

Through its technical publishing, conferences and consensus-based standards activities, the IEEE produces 30 percent of the world's published literature in electrical engineering, computers and control technology, holds annually more than 300 major conferences and has more than 800 active standards with 700 under development.

3.3 Conclusion

The currently designated CENELEC frequency bands clearly do not support a viable high data rate PLC access solution. The designation of higher frequency bands may, or may not, involve other regulatory institutions, dependent upon the technologies applied, the characteristics of the particular network being considered and the resulting degree of electro magnetic emission from those networks at higher frequencies. Based on all available information from current developers of PLC modem technology, CENELEC designated frequency bands between 1MHz and 30MHz would provide a basis for a viable access solution. This frequency range is chosen because below 1MHz, effective separation of the power frequencies from the communication frequencies is impractical because of the requirement for physically large components. Above 30MHz the signal attenuation on a power distribution system is considered to be too high. The designation by CENELEC of a 1-30MHz band would clearly define a basis for viable alternative local access. It would define the preferred basis for other regulatory institutions to seek ways of mitigating the effect of the use of this band by PLC and unlock its potential for the information society.

3.4 Chapter references

[1] CENELEC annual report 1999 (http://www.cenelec.be)
[2] ETSI (http://www.etsi.org)
[3] IEC (http://www.iec.ch)
[4] ITU (www.itu.int)
[5] CIGRE (http://www.cigre.org)
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4 High-Frequency Signals over the Powerline

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PowerLine Communication (PLC) is an evolving technology where the electricity power lines are used as information carriers, offering permanent-access, two-way, last-mile connectivity. Due to the existing powerline infrastructure, extensive geographical areas as well as in-home areas are covered, and it is recognized that the power grid supports information-based services and applications having a strong growth potential.

Different information-based services and applications normally have different requirements on the information transfer. Some will contain information that must be extremely well protected against channel impairments (e.g., control commands and bank contacts), while some applications can accept less protection (e.g., a telephone conversation). There are also significant differences in the amount of data to be transferred and the real-time requirements between different services and applications. As examples we have real-time (on-line) telephone conversation which requires an information transfer at a speed of roughly 15 kbps, real-time video requires roughly 1.5 Mbps, and off-line video which can be considered as a pure file downloading procedure with no stringent real-time demands.

Applications of today (typically meter reading, status and control messages, tariff switching, etc.) can be regarded as the first step towards more advanced applications concerning information exchange over the power line. It is well known from experience that if users are provided with convenient access to high capacity communication links, then a variety of new services and applications will evolve.

4.1 Information bit rate, signal bandwidth, and signal-to-noise ratio

Power line communication is based on information-carrying electrical signals that propagate over the power line. Depending on the technique chosen, the digital information can be represented as, e.g., amplitude-, frequency-, and/or phase-changes. An important property of the electrical signal is its bandwidth, i.e., the width of the frequency interval, around the carrier frequency, that is occupied by the electrical signal. The importance of the signal bandwidth must not be underestimated, and the reason is the close relationship that exists between information bit rate and signal bandwidth: the information bit rate used (in bit/sec, alt. bps) is proportional to the signal bandwidth (in Hz). The practical consequence of this is that applications that require high information bit rates, in general also require a large signal bandwidth.

Services and applications will evolve that require higher bit rates, and also higher real-time performance. Hence, more advanced communication methods will be required for reliable communication over the power line. Today's regulations in Europe (CENELEC EN50065-1) allocate the frequency bands 3-95 kHz for utility corporations, and 95-148.5 kHz for customers. Advances in research and development (see, e.g., refs. [1] [2] [3] [4]) constantly increase our understanding and knowledge of the power line as a communication channel. This has, among other things, lead to proposals for communication methods within the current CENELEC bandwidth, designed for higher bit rates than is used today. Hence, the bandwidth specified in the current regulations can be used more efficiently in terms of higher bit rates if advanced communication techniques are used. However, to be able to provide high bit rate services and applications, there will be a demand for a revised CENELEC standard, which allocates significantly more bandwidth for communication. To accommodate large signal bandwidths, high-frequency signals are used and typical (rough) values for a 1 Mbit/sec connection might be a signal bandwidth of 2 MHz located around a carrier frequency of 5 MHz. Currently, field trials and investigations in the 1 – 30 Mhz frequency band have been reported.

From a communication perspective, mobile radio communication and power line communication have certain general properties in common. Though important differences of course exist, communication system design for PLC benefits from the development in mobile radio communications, as well as from the general development within the fields of coding and modulation. In both systems we can have time-varying conditions for transmission/reception. In the mobile radio communication case this is due to the mobility in combination with the fact that conditions for transmission/reception can vary significantly with the geographic location. For PowerLine Communication the reason is that the connection (and disconnection) of loads can change the conditions for transmission/reception. Furthermore, both systems suffer from interfering signals of a different nature that disturb the communication.

The research and development within the field of coding and modulation has in general reached (and in some aspects passed) the level of knowledge required by the communication channels described above. We see today a development of technical solutions for mobile communications that significantly improve the performance each time a new generation is introduced. The requirements on power line communication systems concerning reliability, bit rate, and real-time performance imply advanced technical solutions where high-frequency signals located within a suitable communication bandwidth are used.

The available communication bandwidth has been stressed above, as a parameter of central concern for high bitrate applications over the powerline. Another parameter of fundamental importance is the signal-to-noise ratio at the intended receiver (also in mobile communications). Here signal attenuation plays a major role, which in turn strongly depends on the communication distance between transmitter and receiver. Hence, the signal-to-noise ratio can be significantly reduced at receivers located far away from the transmitter. The practical importance of the signal-to-noise ratio is that reliable communication, with high bit rates, can be realized when the signal-to-noise ratio is high within the communication bandwidth. Similarly, reliable communication over large distances (i.e., a low signal-to-noise ratio within the same bandwidth) in general requires powerful coding techniques combined with a reduced information bitrate, unless repeaters are used. Hence, not only does the available bandwidth govern the bitrate that can be used, but so does the signal-to-noise ratio at the intended receiver. However, the available bandwidth is in general the single most important parameter for making high bit rate applications possible.

In power line communication there are several factors that affect the signal-to-noise ratio at the receiver. The attenuation of the information carrying electrical signal, as it propagates along the cable, can be too large if the communication distance is too long. Furthermore, the electrical characteristics of the power line between the transmitter and the receiver can often be modelled as a filter, and this imply that the received signal can be described as a filtered (distorted) version of the transmitted signal (actually this kind of model is also often used to model the mobile radio communication channel). It should be observed that the electrical characteristics of the power line communication channel depend on the set of loads currently connected to the power line. Hence, the loads affect the received signal-to-noise ratio, which in general is both frequency dependent within the communication bandwidth, and time-varying. Several of the interfering signals are generated from the connected loads and, hence, they have different origin and characteristics, e.g., periodic signals, impulse-type signals, and noise-like signals. If the amount of interfering signals is too large (i.e., a low signal-to-noise ratio), the receiver will have difficulties in reproducing the original information with sufficient reliability. This is a typical situation in a low-quality connection.

4.2 Technical considerations

To obtain knowledge of how the power line acts as a communication channel in the high-frequency range, measurements are made within the frequency interval of interest (e.g., 1-30 MHz). Properties that have to be measured are, e.g., signal attenuation, cable impedance, interference characteristics, the duration of the channel impulse response, and the time-variation of the transfer function. Some results are available in the open literature. Efficient coupling of the high-frequency signals to the powerline, and the reverse operation at the receiver, is also an essential part that has to be considered in the overall communication system, and different technical solutions have been proposed.

In general, measured results only represent the situation at the specific geographic location and time where the measurements took place. Consequently, measured results from a specific communication channel cannot directly be used to precisely characterize another channel. It may seem that this will reduce the significance of the measured results. Fortunately, from a communication perspective, a complete knowledge of the communication channel is neither required, nor possible due to the time variations. Measured results are used to model specific channels and to obtain “rules of thumb”, i.e., gross quantities such as “the average channel characteristics”, “the average channel quality”, “the average time-variation” etc. Though approximate, such quantities play an important role when deciding the preferred choice of communication technique.

A general rule is that an efficient communication device should be tailored to the properties of the communication channel. Hence, if fluctuations in channel quality are large, the technology should be able to adapt to changing channel conditions. It may be, for example, desirable to transmit more information when high-quality intervals exist. To be able to adapt, the channel quality has to be known, and one way to solve this is basically to use the same strategy as is used in modems for advanced high bit rate applications. The advantage of such an adaptive structure is the potential for efficient communication over a wide range of channel conditions. Typically, good channel conditions imply relatively high information bit rates and modest coding, while significantly reduced bit rates combined with powerful codes are used for low-quality channels. A possible approach to improve the quality of the communication channels is to make additional installations in the grid (e.g., signal conditioning units). The aim is then to increase the level of quality (especially for the worst channels), and to reduce its fluctuations. Methods based on additional filter installations have been proposed. However, it is not quite clear today if the advantages, in terms of system design, bit rate, and reliability, obtained with this approach justify the costs for the additional equipment.

An alternative important design philosophy is to focus on less adaptable, but robust communication systems. By this is meant that the transmitter and the receiver are designed for reliable communication over a broad range of channel conditions. However, the transmitter is fixed in this case, and only the receiver adapts to different channel conditions. The price paid for robustness is in general a lower bitrate compared with the bandwidth used. However, communication systems based on this principle are found in many applications, e.g., digital mobile telephony. Very robust communication can often be established with spread-spectrum techniques. Robustness is here obtained by using a large frequency diversity and hence, the cost of this method is a significantly increased bandwidth.

Though it is true that an adaptive communication system is technically more complex than a fixed, it should be observed that adaptation is mainly a matter of different software configurations. Furthermore, since the cost for fast signal processing steadily decrease, an adaptive structure should at least be considered, due to its potential for significantly better communication performance and for the potential to adapt to future needs. Furthermore, such a system could easily be upgraded remotely and adapted to application specific communication requirements.

4.3 Summary

Based on the discussion above, it is clear that there are several choices that have to be made concerning communication system design. There are also several technical issues of importance that have to be addressed, such as: developing standards, couplers for high-frequency signals, coding, modulation, packet-data transmission, multi-user systems, etc. Though important differences of course exist, communication system design for power line communication benefits from the development and advances in mobile radio communications, and in high bit rate modem design. Examples of key parameters are the available communication bandwidth, and the signal-to noise ratio at the receiver. Several well-known communication methods are possible candidates for future use in powerline applications. Examples are OFDM-type methods, GMSK-type methods, and methods based on spread-spectrum techniques.

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5 Baseline Set of PLC Services

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In order for a PLC service to satisfy a significant proportion of today's communications requirements in the residential and small business sectors, there are a minimum set of services that a customer expects. A successful PLC system must be capable of initiating and/or supporting these services.

From the perspective of the potential PLC service provider, demand for these services is either satisfied directly by the PLC provider or routed by the PLC provider through the public switch or ISP. This minimum set of services is a complex of competitive offerings, market positioning and the physical limitations of the PLC system.

Currently we do not know of any high bandwidth services being provided on any commercial power line network anywhere in the world. Certain trials are providing telephony and data access, but not on a commercial basis. A minimum list of services which would be expected to be delivered from a telecoms provider using PLC can therefore only be theoretical based upon a range of services which are currently available using other transmission technologies. It is true to say that Powerline may well, in the future, provide a suitable alternative access platform, although this has yet to be proven and demonstrated.

The demand for bandwidth within the residential and small office/home office (SOHO) environments is undoubtedly escalating at exponential rates within developed countries [1] , giving rise to opportunities for data services within those territories. We must however not overlook the fact that the majority of the world's population live in relatively low teledensity areas, where even the most rudimentary telephony services are simply not available. Powerline technology, in its most basic form, could well make a major contribution to telephony services in these low teledensity areas.

Services which might be considered fall into the following three key categories:
1. Telephony.
2. Telemetry and utility-related services.
3. Data services.

5.1 Telephony

5.1.1 Voice

The provision of voice services over PLC has been successfully demonstrated by NORWEB in Manchester, UK, between 1995 and 1998. The application employed was an adapted CT2 mobile radio system specified by NORWEB, modified and supplied by NORTEL.

- Around 25 residential customers were given 32kbit digital voice service. A number of these customers also used the service for Internet access using a dial up modem.

- Service quality improved dramatically after the first six months. The majority of service faults resulted from faults within the customer premise equipment. After twelve months, acceptable service was approximately 98% of all connections.

- The equipment operated at frequencies between 8MHz and 12MHz. (In normal mobile operation it would have operated around 900MHz) [2] .

While this trial could be described as crude (returning a very low number of bits/Hz - in the region of 0.05bits/Hz), it adequately demonstrated the concept and resulted in a high level of customer satisfaction. Although the service was intended to provide a second line, many customers discontinued their original twisted pair connection, relying entirely upon the Powerline service.

Because of the need for real time data, delivery the provision of voice services over power line is considered to be onerous. This is not because of the demand for bandwidth, but for the fact that the customer is intimately aware of any incident, no matter how minor, of noise interference on the line. The customer using PLC for data traffic, on the other hand, is generally unaware of any momentary interference. The fact that NORWEB were able to deliver a viable, although crude, voice service, which met and exceeded the expectations of the customer over a period of years, establishes the reasonable expectation that a quality voice service can be delivered over PLC. It is interesting to note that the reported faults were associated with the customer premise CT2 equipment and not the integrity of the power line connection.

Building on this experience and looking toward more sophisticated equipment, it is reasonable to consider that the following basic services should be expected and can be delivered.

5.1.2 Person to person

- Residential calls

This is the provision of services within the local loop and connection to long distance carrier. The usage for residential purposes varies considerably between the lowest and highest usage in this category. An international benchmarking study of telecommunications services prepared for Oftel [3] provides a useful insight into this sector. This primary line sector of the market already has very high penetration, probably approaching saturation within developed areas [4] . Secondary lines, however, are presenting a high growth sector within the residential market. This is driven by major changes in lifestyle, which have increased family telephone traffic due to the trend towards the dispersal of families throughout the larger community. The availability of telephone accessed services is also increasing demand. The greatest generator of demand for increasing the number of residential lines is the use of the telephone line for dial-up Internet access [5] .

- Business calls

The growth of small office, home office (SOHO) in the Community has further increased the demand for extra lines in the residential, non-industrial areas. This phenomenon is being driven by increasing costs of transportation, city centre overheads and the need for increased efficiency of human endeavour. These changes are also functions of basic social changes taking place, which demand equal work opportunities for all members of society and the economic benefits this delivers.

- Emergency service calls

Offering telephony on PLC as the primary communications service will demand very high levels of reliability. This demand is likely to exceed the reliability of the power distribution network and may fail to meet national criteria for a primary service designed to support emergency service calls.

5.1.3 Person to pre-recorded data - Public information

Consumers are increasingly able to access person to pre-recorded data services, which are gradually becoming considered essential as they are adopted into daily use. Most of these services will be accessed by the PLC network through the public switch and would generally be supplied by third parties, usually on a premium rate basis. These optional premium non-essential services might consist of:

- Weather forecasting/Tide-tables/Traffic
- Entertainment
- Sports results
- Travel information
- Shopping
- Voting .

The bandwidth required to deliver these telephony services may be affected when simultaneous demand for connection is instigated via broadcast or special events and circumstances. Adequate capacity to cover reasonable fluctuations in peak load would need to be monitored and made available. In extreme circumstances it may be necessary to allocated bandwidth resources to particular uses in preference to others.

- Directory enquiries

This basic service is probably the most widely used person to pre-recorded information service, although it is instigated by person to person communication it is delivered by a pre-recorded to person communication. This service would be expected to be sourced from the PLC provider.

5.1.4 Pre-recorded data to person

As in person to pre-recorded data, most of these services would be provided via the public switch and adequate bandwidth would need to be provided to meet the demands of those services. These may include:

- Governmental transmissions
- Emergency alerts/Security alerts.

The PLC service provider would need to directly serve the needs of its customer in relation to alarm calls and voice mail.

5.1.5 Operator services

Telephony customers have come to expect operator-provided services to include:

- call diversion,
- call waiting,
- call barring,
- call return,
- caller identification and display,

- number withheld,
- ring-back,
- voice mail,

- operator connected calls,
- reverse charges,
- alarm calls/reminder calls,
- credit card calls,

- national operator,
- national directory enquiries,

- customer service,
- charge advice,
- fault reporting,
- sales,
- itemised billing,
- help desk.

The following would not essentially be provided by the PLC provider but could be offered as a means of developing extra revenue streams from PLC telephony.

- three-way calling and conferencing,
- international operator,
- international directory enquiries,
- Multiway calling
- Group distance learning
- Business applications.

5.1.6 Facsimile transmission

Customers expect to be able to use their telephony connection for facsimile transmission at data rates between 9,600 and 28,800 bps. This would support:

- Fax Image transmission
- Image broadcasting
- Image fax back
- Optically encoded data images.

In summary, the PLC provider and the PLC system must be capable of supporting and delivering the above services in terms of bandwidth availability, reliability of connectivity and direct customer services. For a basic telephony service the PLC provider will need to make provision for a bandwidth of 3.1kHz/customer on demand.

5.2 Telemetry and utility-related services

The PLC provider would place high priority to the bandwidth allocation of the telephony service. Policies regarding the allocation of bandwidth priority will need to be developed by the PLC service provider in consideration of the perceived importance of the bandwidth request. This factor indicates the need to provide and maintain a reliable, sophisticated and practical traffic management system on the PLC network.

In relation to telemetry and utility related services, the PLC network would have several customer groups. These will include residential customers, SOHO customers, the power and other utilities and external service providers.

5.2.1 Residential and SOHO telemetry services

The introduction of value added services for consumers have increased the need for bandwidth in the residential market. It is now possible to purchase, via the remote control of a set top box, a wide variety of consumer retail products. Provision of this telemetry service is seen as an essential offering of any successful PLC system. The PLC system has many advantages over more traditional communication methods for delivering data associated with security applications. These advantages stem mainly from the fact that it is much more difficult to interfere with the channel between the customer and security service provider as any disconnection of the channel would involve exposure to potentially lethal voltages.

5.2.2 Power utility related services

Although the PLC network is based on the power distribution network, it will be able to provide services to the power network operators to improve the safety and efficiency of the power network. The value of these services will need to be determined by the power network operator, but are likely to be fall within the minimum set of services likely to be required from the PLC network. These services will include:

- Network switching
- Network monitoring
- Fault diagnosis
- Demand side management of power distribution network

- Remote load control
- Tariff switching
- Meter reading telemetry.

5.3 IP data services

The provision of data services via the PLC medium is seen as an essential component to any viable service being offered and within the minimum expectations of the residential and SOHO customer. It covers the following service offerings.

- Internet access

- World Wide Web

The increase in data traffic associated with Internet connection is a major focus of service provision through the PLC medium. The majority of residential and SOHO customers gain access to the Internet using a dial up connection to a maximum of 56k over a POTS connection. This is rapidly becoming considered to be inadequate for the increasingly sophisticated content of the World Wide Web. Other wideband technologies are beginning to address this access bottleneck although these technologies suffer disadvantages of cost and lack of ubiquity.

- Email

Bandwidth requirements for Email service are generally low, although Email and WWW access are invariably inextricably linked in the mind of the end user. For this reason the PLC medium must be able to offer both WWW access and Email concurrently.

- File transfer

File transfer is the third aspect of the Internet. It is perhaps less utilised than both WWW and Email but is invariably the application which accentuates the limitations of dial up telephony based connections. With an increasing demand for downloading large data files containing software, images, video, sound and general documents, any data connection must provide adequate bandwidth to satisfy customer expectations in the residential and SOHO domain with regard to this functionality.
The minimum requirement for Internet connectivity within the local loop is a bandwidth, which will provide a satisfactory Internet experience for the user giving due consideration to the availability of content over the Internet beyond the local loop. It is unnecessary to provide bandwidth to the user over the local loop, which is substantially in excess of that necessary to keep pace with the rate of content delivered from source. The allocation of bandwidth per customer on the local loop for Internet access would be adequate at a level of 0.5Mbits on demand and, giving headroom for future developments in content and Internet performance, a level of 1.5Mbits is seen to be more than adequate [6] .

- Local area networking

Because of the inherent “cell like structure” of electricity distribution networks, there is an opportunity for PLC to offer local information to the local community via a local area network serving the cell, or groups of cells, on the PLC service.

Content can be held on local servers and would not be subject to many of the inherent problems associated with placing those services on WWW. This application has particular merit in relation to local government and to local retail which can deliver highly accessible content at high speed and low cost within the PLC system. This concept gives rise to the idea of the information utility, where the utility would cache large amounts of popular Internet content for rapid delivery over its network. This content would have quality assurance, which is increasingly being demanded by family customers.

- Video

Scheduled video on demand providing MPEG2 video streams on the PLC system, served from the PLC service provider is seen as a service, which will be considered a minimum requirement within the next 5 years. Any PLC system would need to be dimensioned to enable it to provide at least 3 simultaneous video streams which would occupy 5Mbit (uni-directional) of the PLC system.

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6 Expanding the Set of PLC Services

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Innovative and differential services raise two key issues in any proposed rollout of service offerings to the target market. Innovative embodies those services which address specific aspects of personal and business life which provide improvement either in terms of cost, efficiency, ease of use and those which make a direct contribution to the improvement to the quality of life.

‘Differential’ would refer to services, which can be differentiated in the way they are presented and not necessarily innovative or particularly different from services already available. For example, the unbundling of local access telephony services, say in the United Kingdom, results in 15 individual companies using the same primary technology attempting to differentiate themselves from each other. However, a Powerline service perhaps even offering identical services is capable of differentiating itself simply by virtue that it is a service which is carried on Powerline. Although technically this has absolutely no merit, from a marketing perspective it can mean the difference between success and failure.

The following could be described as a ‘blue-sky’ list derived from the reality in the baseline services outlined in chapter 5, but produced as a possible source of stimulus to those who may wish to consider some of the future uses of the Powerline platform of telecommunications.

6.1 Urban GSM network extension

Recent concerns regarding poor GSM availability in dense urban areas and the possible harmful effects of powerful UHF transmissions could well open considerable interest in extensions to the existing GSM network by using PLC technologies to deliver urban GSM signals through the existing power distribution network. Utilizing street lamps as antennas inked to a power line back haul to produce mini cells for the existing GSM network, could significantly reduce power levels needed for existing GSM telephones in urban areas. This approach could also deliver a much improved access to the GSM network in urban areas by creating a large number of mini-cells enabling GSM equipment to operate at significantly reduced powers. The proposed approach would be to connect antennas and frequency conversion equipment located on street lamps adjacent to each urban substation to back-haul equipment located at the substation. Due to the short distance between the substation and the adjacent street lamps, a frequency of band of 30MHz to 150 MHz could be employed without creating unacceptable emissions and avoiding the proposed 1 to 30 MHz band used by PLC. Installations could be achieved with minimal public disruption and probably at relatively low cost.

6.2 'Leaky feeder' technology-based services

'Leaky feeder' technology-based services use the electricity networks to provide antennas and connectivity for mobile communication equipment.

The radiating characteristics of high frequency, higher power PLC can be used to advantage by using the signal emission and ingress of the power network as a positive feature used in the transmission of signals associated with a range of innovative applications. Based on the 'leaky feeder' approach, the following services could be supplied:

- Telephony in buildings and areas of poor/saturated GSM cellular coverage, e.g., cities, airports.
- Mobile intercom facilities within the curtilage of an establishment for the purpose of providing information (in the case of museums, hospitals, schools, government buildings, entertainment establishments, monuments, sites of historic importance, etc).
- In-vehicle communication, aircraft, ships, buses.
- Offender tagging monitoring.
- Animal tagging monitoring.
- Vehicle position monitoring.
- Zone access monitoring – city traffic and other enforcement legislation.
- Local emergency system (e.g. personal attack alarm).
- Police use
- Paging.

In all cases the benefit of using existing power networks to provide a platform for the above applications is the ubiquity of the power system, the relatively low power needed to sustain a communication, the limited cost of achieving the application and the low public disruption associated with its installation and maintenance.

Frequency bands would need to conform to already allocated frequencies for private mobile radio or be assigned new frequencies such as disused VHF broadcast bands. Bandwidth required for the above applications would be small since they are based on voice and low data rate traffic. It is considered that a bandwidth of not more than 0.5Mbits/s would be adequate.

6.3 Security Applications

PowerLine Communications has unique attributes in the field of security applications. It is inherently secure at the lowest physical level, e.g. eavesdropping and unauthorised signal removal and interruption is difficult and dangerous. These attributes give rise to the following innovative and differentiated applications:

- Connection and control of passive and active alarm switches to the central processing unit in building. Very low data rate, down to bits/minute.
- Remote monitoring of the local security nodes. Very low data rate down to bits/minute.
- Video and audio surveillance. From a security perspective, high quality surveillance video can be achieved using data rates of 2.5Mbits/second. This would provide video quality similar to VHS. For most security applications this

level of quality would be excessive and adequate surveillance could be achieved using a low frame rate (4-8 FPS) at lower resolution, 320 x 240 pixle screen resolution. This application could be achieved at 200kbits/second.

- Video equipment telemetry. Very low data rate necessary for camera control in the order of 10’s of bits/second if feedback is required.
- Access control telemetry and monitoring. As with video equipment telemetry.
- Remote enabling, disabling and logging of individual access routes for general site control. As with video equipment telemetry.
- External barrier and gate control and communications; 10kb/second when associated with voice communication.

In all the above applications the primary advantage of using PLC is in the ease, speed and cost of installation, coupled with the added security afforded due to the communications being carried on live power distribution cables.

6.4 Fast Internet access

The opportunity for the power distribution company to become a internet service provider has obvious commercial advantages to the power distribution company and opens up a whole range of services which can be carried on Powerline for access to the internet and to cached serviced supported by the power utility ISP.

Probably the greatest opportunity over the next decade for power utilities will be the emergence of the information utility. The information society consumes information in the same way that it consumes electricity, gas or water. And the commodity of information needs to be harvested, generated, refined and purified, collected, reserved and delivered, on demand, instantly in abundance; this is the role of the information utility. In addition to providing a whole range of important local services relating to public welfare, government, participatory democracy, voting, banking, shopping, video conferencing, security, meter reading, heating and energy control, the utility is able to cache internet content from all corners of the world, categorising and refining in order to provide instant access to popular sites which would normally involve the all too familiar W*orld Wide Wait.*

6.5 “Smart” in-home, energy, and building management services

We distinguish two types of services, which require different technical levels of operation:

- Broadband services: telephone, Internet and mailing, video on demand, LAN networks. Broadband services require high data transfer and high fault tolerance level.
- Narrowband services: metering and control. Narrowband services will normally operate at lower transfer rate.

This section focuses on narrowband services for in-home and building management functions. The division of the services (metering, information exchange, control) is based on technical choices which will be elaborated in the PALAS deliverable D9 on software architecture. Other divisions are possible.

6.5.1 Metering

Metering services basically deliver one-way information from customer to the servicing organization.

1. Remote or Automatic Meter Reading, the remote collection of consumption data from customers' utility meters [1][2]. AMR provides electric, gas and water utilities with the opportunity to streamline metering, billing, and collection activities and to enhance service to customers and gain a competitive advantage. AMR also provides detection of tampering and/or energy theft.
2. Remote Metering can be extended to remote collection of other data types, such as measuring of online buffer contents in order to control supplies. These measurements can be used to schedule intelligent provisioning. In the recent past ECN has performed a study on control of gas supply in deserted gas tanks. Telecommunication costs proved to be too high because of lack of infrastructure. Power line availability might alter this conclusion.
3. Performance monitoring. Examples are: power quality, outage detection, appliance diagnostics, gas flow and quality, pipe corrosion, indoor air quality, coordination of fuel switching (Wacks [3]).
4. E-commerce trading. Online energy pricing can be used for optimized energy purchasing.
5. Forecasting. Prediction of usage may help optimizing energy production and purchase. Knowledge of usage statistics is a main source on which these predictions can be made.
6. Revenue protection, the detection and reduction of non-technical losses. Historically utilities tend to pass distribution losses by adjusting the energy rates. Deregulation and competition will change this view. Also theft and fraud is often underestimated by utilities. Especially in developing countries revenue protection is already a major focus (Singhal [4]).
7. Building Performance Assurance (BPA) addresses three broad issues: Diagnostics and Commissioning, Performance Metrics and Benchmarking, and Life Cycle Tools. The long-term goal of the these projects is to provide building decision-makers with the information and tools needed to cost-effectively assure the desired performance of buildings, as specified by principal stakeholders, across the complete life cycle of a building project [5].

6.5.2 Information Exchange

Another aspect of metering is the feedback of information to the customer. One aspect of feedback is the awakening of the customer consciousness by letting know how s/he is doing.

1. Real Time Accounting, based on time of usage.
2. Validation of contracting / Quality assurance. More and more contracts between utilities and clients will decide on energy prices and quality. Insight in detailed usage figures helps both the utility and the client to draw up an optimal contract and to validate the contract regulations.
3. Usage statistics, visualization and analysis give insight in energy demand and usage to both the service organization and the customer.

4. Advisory services. Utilities are taking up a position as energy adviser. They have an advantage on the competition once they have knowledge on their customers.

Metering and feedback-of-information services can be directed towards residence homes but will also be applicable towards industry, esp. SOHO's.

6.5.3 Control

Control services are based on two-way data transfer. The data-transfer from the customer to the service organization is based on the same model as used for monitoring services. The data-transfer to the customer is meant to influence the customer site by making more or less autonomous decisions.

1. Control of energy generation and usage: DSM.
   - optimization of E-net
   - buffering

   Tuning of supply and demand in residential areas with local supply (solar, CHP, heat pumps); storage and buffering should be available.
2. Load management. If load can be scheduled, controlled demand leads to more efficient energy usage distribution and can avoid peaks in usage.
3. Energy Service Contracting. Validation is an important factor.
4. Home security. Protection of people and goods in different situations, which may occur in the house: fire and smoke detection; burglary alarm; technical alarm (water, gas, …); light control; simulation of inhabitation.
5. Home help for the elderly. Detection, control of operations (e.g. cooking), communication with social or health care, etcetra.
6. Home Automation and Home Networks. Home automation captures intelligent systems which enhance the comfort, efficiency and communication in-house. Home automation systems are often seen as local, in-house, systems. Combination with local access allows added services such as remote security control, remote installation, control of parameters, etcetera. Echelon [6], Coactive Networks [7], and emWare [8] provide gateways to connect the home network with the Internet for remote access. In Japan the ECHONET gateway system [9] is developed in which services such as security and home help for the elderly are combined with central control of home appliances (air conditioner, washing machine, dryer, refrigerator, etc.).
7. Individualized energy management. Preference for energy mix (green energy, non-nuclear energy, cost-based).
8. Performance management. Appliances maintenance, outage detection Kansas City Power & Light [10] offer a so-called Worry-Free Service, in which maintenance (including on-time substitution) of equipment is offered, which will save the customer "up to 35 % of your heating and control bill". KCPL is no longer delivering electricity and gas but delivers a comfort service.
9. Comfort management, i.e. the maintenance of a desired temperature and air climate in each room or office. In the TRAFO project (Free University Amsterdam, ECN, HKR Ronneby, Enersearch) a prototype Comfort Management System [10] has been developed, in which information on weather, building, user preferences and energy prices is used to optimize the comfort in a building automatically by Internet software agents. Simulation shows that energy savings up to 20 % can be reached in typical consumer

scenarios [11]. Some further international work on PLC and advanced services it can offer is reviewed in a EU advisory report of 1998 [12].

10. In case of non-payment by a customer the utility can cut off energy delivery. However, it might be socially unacceptable to cut off someone during severe cold. Allowing only a minimum comfort level can be a way for a utility to perform its social duty.

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7 Customer Service and Operational Cost Issues

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7.1 Deregulation and Its Impact on Customer Service Models and Operational Cost Dynamics

Customer service and operational cost issues for PLC services must be reviewed from a business and service model perspective. PLC services provided by utilities broaden their enterprise models to more than simply providing 'electricity to a building.'

This section offers a dynamic market and service model perspective on customer service and operational costs associated with PLC services in deregulating power markets. Long-term administrative and equipment costs and changes in customer service models for PLC services can only be speculated upon since many of these services do not yet exist in the electrical industry. Therefore telecommunication businesses such as fixed wire telephony- and mobile-services are analysed in this section for they (1) pre-date and reflect well cost and service model dynamics facing electrical utilities, and (2) offer insight as to how these service and cost dynamics vary over time as competition increases due to deregulation. In later sections we offer richer detail about specific operational and cost issues associated with PLC services.

7.1.1 Customer service cost dynamics

Customer service costs presently fall into two main categories for utilities: (1) administrative and (2) infrastructure.

Administrative costs

When there was little variation in the type of subscription available, there was little variation in costs associated with serving subscribers. Prior to deregulation, customer service was (and for many utilities is still) not considered customer service at all. It is considered *administration*. Costs associated with administration revolve mainly around: a) opening and closing subscriptions and electrical service to a property, b) the adjustment of estimated usage with actual usage as noted in the field by a service representative, and c) the collection and reconciliation of debts and payment anomalies of subscriber/customers.

Infrastructure Service Costs

Field (customer) service is considered service and maintenance of the network infrastructure, not necessarily service of a customer, per se. Service variables related to differences in customer demand vary mainly around the amount, strength, and sometimes quality of power delivered to a property. Greater power, cleaner power and total amount of consistent power used (which may vary under different periods of the day, week, month or year) requires specific equipment. Once the appropriate equipment (network interfaces, controls, filters, back-ups, safety, etc.) is in place, service turns into administration via large billing systems that administer periodic statements to subscribers. Field services are usually limited to installing, serving, maintaining and reading field equipment. The reading of power consumption meters happens after-the-fact and adjustments to bills are then made administratively with the use of information databases and technology that compare usage estimates with actual usage.

So long as the basic services remain unchanged, the dynamics underlying customer care costs remain fairly unchanged, which has been and continues to be the case for most electricity resellers throughout Europe before PLC and other services have appeared on the market.

7.1.2 Changes in Customer Service Cost Dynamics Due To Deregulation, Competition & New Service Pressures

De-regulation and competition create new market dynamics that impact costs of customer services. These arise mainly as a result of adding new services (as reviewed earlier) but not surprisingly also as a result of variations of relationship/contract offerings. The next sections address 1) cost dynamics related to operating in a de-regulated and increasingly competitive market, 2) cost dynamics related to new service pressures, and 3) a vignette of the mobile telecommunications service industry and its implications for impact on costs of customer services of the PLC-type.

7.1.2.1 Increased marketing and sales costs resulting from de-regulation and increased competition

Marketing and sales costs increase mostly due to:

- Increased advertising activity
- Increasing customer call centre coverage
- Production of greater amounts of sales materials
- Implementation of new market communication channels (like websites).
- Greater customer ‘churn’ (switching behaviour).

Residential customer care prior to deregulation for one utility in Sweden was calculated at less than one call per year per household. After deregulation, these have increased to 1.5 calls per year per household at a cost of approximately 8 EU per call. That is to say, costs have increased by 50% per household per year simply because of deregulation. Multiplying this by the millions of households served by the utility and the increase is substantial.

In general, new customer acquisition costs were not even an item budget for utilities prior to deregulation. On the internet, new customer acquisition costs can reach as much as $700 US [1]. The cost of customer switching is considerable as well. Thus, deregulation brings with it increased marketing-sales costs, clearly, and new costs, entirely.

7.1.2.2 Increased costs resulting from new service contracting models

With deregulation come new forms of ‘subscriptions.’ That is to say, types of contracts for service tend to proliferate from one basic type to many types. Swedish electricity resellers, for example, offer long-term (2-5 year) contracts, short-term contracts, and ‘tillsvidare’ options where anyone can change providers nearly at will (see www.sydkraft.se,, www.vattenfall.se, www.birkaenergi.se for examples). Each contract model impacts sales, marketing and administrative costs positively. That is, simply introducing variation increases costs.

7.1.2.3 Increased costs resulting from new distribution models, partners and networks

Increased competition tends to create incentives for innovation in marketing channels. This is true for telecommunication and electricity service reselling channels as well. Buying clubs, internet portals (www.abonnera.com), banks, even oil companies have begun to try their hand at reselling electricity services and contracts. The effect is twofold: lower margins for the producer and perhaps lower costs for reaching greater volumes.

As PLC services become more sophisticated, the role of such partners and the partners themselves will change, likely toward those who have technical as well as sales delivery channels and support networks in place, which is one of the expected offspring of PLC developments.

7.1.2.4 The dynamics of increasing costs related to new service pressures

New services bring with them new demands on customers, resellers, and providers themselves. One can expect that as the number of PLC services increases the complexity of service options and equipment/devices on customer premises, costs associated with, say broadband support, security monitoring, home network support will also increase as a direct result of the addition of new services.

7.1.2.5 Cost dynamics associated with new service billing models

Billing for electrical service has traditionally been based on volume. The more electricity consumed the greater the total cost. Market dynamics will likely change this.

In telecommunications we have witnessed a shift from volume-based billing models to flat-rate billing for local access, for example. In addition, pre-paid billing for scheduled use is also emerging in mobile communication services, and some exploration with 'smart (pre-paid) electric cards' has emerged at times as well. Flat-rate, versus time-based volume prising, versus pre-payment models each have their variable costs, benefits, and drawbacks. A closer look at developments in mobile telecommunications and the evolution of billing, subscription, service, and distribution models provides a background for examining specific cost data available today for PLC equipment, services and usage.

It is also extremely interesting to review mobile telecommunications because some of the services are or could compete directly with those of PLC services.

7.1.3 Development in Mobile Telecommunications and Their Implications for PLC-Type Services

7.1.3.1 Trends in the mobile telephony sector

Ongoing changes in mobile telecommunications are rapidly providing individual consumers and organisations new value added products and services outside the core areas of voicemail, and the small portion of data traffic carried. For example, new business services are emerging, providing individual consumers messaging, news, weather updates, financial updates, entertainment (games, gambling, audio) video, m-commerce (banking, ticketing, share shopping), location dependent services, consumer telemetrics (burglar alarm, child-watch, home automation), and more. A variety of mobile communication applications are expected to improve both efficiency and effectiveness in organisations (linking intranets to mobile applications, for example), and are already beginning to diffuse in many sectors: banking and other services (insurance, consulting), transportation and vehicle industry, manufacturing and building construction industry, trade and retailing, and security services.

The mobile communications industry shows a growing interest in mobile datacommunication. It is generally agreed that the most common way to access the internet within a few years will be from mobile terminals, though the services may be quite different than typical ‘web-surfing.’ In order to facilitate this development a number of different initiatives are underway to improve the communication speed in mobile networks. Europe, and in particular Scandinavia, has taken a leading role in the mobile communications industry. It is widely predicted that in the next five years, the biggest change to the mass market Internet will be wireless, making cell phones full Internet citizens and adding a new location-sensitive dimension to a wide array of information services. It is predicted that GPRS, the new standard redefining the mobile Internet and providing a truly global, always-connected IP service, will happen first in Europe. And Scandinavia, being one of the most advanced mobile markets in the world, has been put forward as a central innovation node and service testbed, one year ahead of e.g. the American market. The industry already has plans and ideas for the third and fourth generation mobile systems. Although mobile communication suppliers have dominated the mobile market hitherto, they will meet a growing competition from IT companies and Internet related companies, and some of their services may be effectively in competition with PLC.

Mobile telephony will continue to grow in different ways in Europe, and the services and business models that emerge will likely compete or migrate to other utilities in coming years. The number of active users will be an important measure, while the emergence of cash card customers, machine-to-machine interaction etc., will make simplified penetration measures difficult to apply. In addition, the private sphere and the work sphere will continue to change, like the borderline between the two. In these spheres, mobile telecommunications will be important backbone, but a wide array of other services and service suppliers (fixed net operators in the telecommunication and energy sectors, banking and other actors active in payments and billing, and many more) will be involved in these rapid changes.

Next we present a set of specific issues related to trends in the mobile telecommunications sector. It is assumed that these issues have important implications for how activities both in the private, family sphere, and in the organisational, work sphere, will develop in the future.

7.1.3.2 New value added services and advanced services

It was described above how the development in mobile telecommunications and the emergence of mobile data and mobile internet services have provided consumers new value added services: messaging, news, weather updates, financial updates, entertainment (games, gambling, audio) video, m-commerce (banking, ticketing, share shopping), location dependent services, consumer telemetrics (burglar alarm, kid watch, home automation), and more. So far, however, voice communication is still the totally dominant activity among customers.

However, it is generally argued that the potential to develop a large number of new value added services for both the private, family sphere and the organisational and public work spheres is considerable. For example, with GSM systems as technological base, the telecommunication industry has already started to develop advanced industrial services for machine-to-machine interaction. Many new value added services with the potential to radically increase both efficiency and effectiveness in many industrial sectors are expected to be developed within the next few years. Taken together, the development of these new advanced services will in some cases radically change the industrial structures both on the supply side and on the user side. We can already today see a number of new, more or less unexpected, strategic alliances being formed between companies in formerly unrelated industries. This development will most likely be accentuated in the future.

7.1.4 Implications for the future

From a mobile telephony and mobile internet/mobile data perspective, we can see the emergence of a new generation of integrated mobile system solutions. We present four central issues:

There is interdependence between “mobile” and “stationary” aspects of “mobility solutions”: Mobility in use cannot be discussed and analysed without including its opposite. In fact, in many of customer cases, increased mobility of some parts of the user organisation is based on the fact that other parts could be made more stationary, but interactive and ‘communicable’.

What “users” are driving changes towards increased mobility? Three types of users and user situations are seen to drive increased use of mobile data solutions: 1) The individual/the private consumer, 2) the individual as part of an organisation, and 3) the organisation. Mobile providers focus much on 1 and 2, but less on 3, at the moment. Representatives of the industry suggest however that area 3 offers huge potential, and some of these could well be in concert with other ‘fixed’ providers.

The datacom and telecom sectors are organised according to different logics compared to utilities. What is the effect of that on PLC service provision and cost developments? The spread of telecom and datacom business models and practices to utility industries and visa versa, due to service convergence, is a likely co-concurrence to PLC development. Telecom pre-paid billing logics, for example, may increasingly become visible in PLC billing logics. Flat-rate or pattern billing models in place in residential electrical utilities seem to be spreading to telcos. And flat-rate billing for residential (apartment) electricity customers serve to reduce administration costs for utilities, perhaps more than near-real-time-billing based on remote meter reading could capture.

The race for datacom and telcom actors to become the “real time IP carrier class” actors will also influence PLC deployment and operation costs. Who will be the new, important system integrators? Overlapping of industrial networks leads to constantly new patterns of competition and co-operation. Supply of PLC that incorporates Internet capability will surely make the medium attractive to existing IP service providers. How the supply side handles these aspects is a central issue for further research, but it assuredly will impact PLC provision as eventually PLC will technically interface the internet and IP carrier standards, media, and markets.

The role of new value added services in the links between the suppliers and buyers is a forth issue: How will utility actors handle the situation when services successively lose value and become taken for granted like ISDN (or near broadband capacity) will soon be in many households? As mobile telephony internet access services become ‘standard alternatives for users,’ network operators will search for new value added services, which will likely be targeted toward machine-to-machine and other applications. There is clear opportunity for a mobile operator to develop remote meter reading as the cost of a simple data-send device drops to costs less than those being offered on the market today for LONWORKS® and other technology. At the same time, system integrators from other parts of the industry will be able to integrate mobile telecom services in their packages to customer organisations and residences. These processes, including the emergence of new service packages, are important driving forces for change.

In the next section we examine more closely operational service cost issues and elements specific to PLC.

7.2 PLC Service Elements, Customer Motivations and Segments, and Cost Dynamics Specific to PLC Service and Business Models.

The utility enterprise’s business model depends on the nature of the services offered *and* the customer’s motivation to adopt and use them. Service costs are directly related to customer preferences and demand for different service offers. It is the constellation of services and their design, as implemented by a given utility, which constitutes the utility’s business model. Some designs incorporate customer labour and investment (like updating of equipment on premises or changing of behavioural patterns to better manage demand) and thus influences operational and service costs. We review briefly the category of PLC services and customer incentives associated with them, then proceed to specific PLC cost element data available today including a summary literature review of PLC services.

7.2.1 PLC service

Recall that we distinguish between two categories of PLC services, which require different technical levels of operation:

- Broadband services: telephone, Internet and mailing, video on demand, LAN networks. Broadband services require high data transfer and high fault tolerance level.
- Narrowband services: metering, information exchange & control. Narrowband services will normally operate at lower transfer rate.

The division of narrowband services (metering, information exchange, and control) is based on technical choices, which will be elaborated in the software architecture deliverable of the PALAS project to be delivered at a later date. Other divisions are possible. There are different target groups and different customer incentives for services of broad- or narrowband types. We now turn to the customer aspects influencing PLC deployment of both narrow and broadband services.

7.2.2 Customer Aspects

7.2.2.1 Customer Motivation

A critical factor to successful implementation of new services built upon PLC is customer acceptance and willingness to exploit service possibilities. We see the following incentives for PLC services as described above:

- Customer cost savings.

Many PLC services consist of offering new ways of doing existing business. The customer will be interested in these services if he *knows* that it will save him money. The emphasis lies on 'knows' because the customer has to be convinced that the pay-back time for his investments will be less than 3 to 5 years. Investments might be written off by charging a monthly flat rate, which should be less than the customer's savings.

An example of a service directed at customer cost savings is energy management. By delivering optimal energy service to a customer he will be able to save money. Although it is not the first goal of a utility to 'sell less' he will be able to attract new customers (or to keep his own customers) by offering energy saving services. Price competition is a main factor in this.

- Utility cost savings.

The service consists of offering new ways of (the utility) doing existing business. An example is Electronic Bill presentation and payment, or *e*-billing. The bill is presented online and preferably also paid online. E-billing saves the utility money. The customer has no direct interest in saving the utility money, unless the customer participates in the savings or experiences some added value from the service. Added value for the customer provided by e-billing can be detailed and richer information that can be presented on the Internet or direct online payment. Both services rely on automatic meter reading – a narrowband service. (For a US example see Kansas City Power & Light, http://www.kcpl.com/).

- New Services.

New services should be offer new possibilities. Customers will be interested in new services if they offer value. They may also resist them if it requires investment or a change of habit. To introduce new services, it may be required to 'give away' equipment that enables new services, in order to lower barriers to their adoption. An example of this kind of tactic is that of mobile telephony. Telecom utilities have been giving away mobile telephones at low prices or even for free in order to build a market for their services.

- Environmental consciousness: beyond direct pay-back.

Some services can appeal to some customers because they promise a 'better world' or in economic terms contribute less to causing negative externalities of using a service or energy type. Financial pay-back on investments made (or on prices paid) is less an issue since the customer is apparently calculating the cost of externalities into the service. Energy savings and especially green energy usage can trigger investments for these customers. An example is The Netherlands 'green energy' project in which the customer pays a surplus in exchange for the utility's guarantee of a percentage of green energy supply. Also in the Netherlands customers make large investments in energy efficiency measures (insulation, energy efficient boilers) and even purchase solar cell home systems which are far from cost-efficient. Thermostat control in homes (15 °C at night; savings up to 10% per °C) is in The Netherlands standard for many families.

- Technology-interested motivations.

New IT-driven services can appeal to technology-interested customers, even if prices are higher than average. The technology-interested market is a niche market, which is characterised by hobbyists, 'techies' and often affluent households. A niche market can be attractive to introduce services that in due course of time mature into full market penetration, simply by spreading development costs from the earlier adopters to later adopters. Development of such services requires thorough marketing research and careful risk assessment/business opportunity forecasting.

7.2.2.2 Target Customer Groups

Next we describe customer segments and their motivations to adopt PLC services.

- Domestic/Residential

Residential customers are a mix of price-conscious, environmentally conscious and technology-interested customers. There appear to be associations of price, environmental, and technology-interested clusters when crossed correlated with location and income/social stratification variables.

- SOHO's (Small office/Home office).
- Service organisations

  In most cases cost-driven, bound to energy efficiency covenants; separate targeting for e.g. environmental consciousness is less useful.

  - office buildings,
  - hotels and motels,
  - restaurants,
  - schools and universities,

  - health care,
  - supermarkets and groceries (and warehouses …),
  - retail.
- Industry
  Cost-driven, bound to energy efficiency covenants. Industries are process-oriented and therefore of a different nature.

7.2.3 PLC-based Service Cost Elements

7.2.3.1 Infrastructure Costs

- Electronics at subscribers premises
- Electronics at local distribution point (substation)

For many narrowband services effective service management can be centralised on the substation level. Only small interface devices will be needed in-home. Once these devices are built into appliances direct customer investment will become minimal. The substation investment in hardware can be shared between all customers, while the software for the services is a one-time effort.

7.2.3.2 PLC Service Operational and Maintenance Cost Elements

Long distance operator interconnection
Electronics maintenance and upgrading
Local access regulations

7.2.3.3 Service Related Costs

Support
Software
Marketing & Sales
Billing & Administration
Training

7.2.3.4 Indirect and Desirable Cost Reductions

PLC Services can reduce expenses. Not only direct savings (e.g. Electronic Billing Payment) can be achieved, but also indirect savings such as medical or social expenditures (home help for the elderly, theft and damage prevention).

7.2.3.5 Degree of Penetration

Electronics are presently intended to be installed at subscribers' premises. That is, for customers desiring a given service and not on not on speculation. However, some 'give always' as noted above may indeed be required to build a critical mass of customers (as with mobile telephony) and to distribute substation costs over expected market penetration shares.

7.2.4 Summary of PLC Literature Survey

Only limited information on cost elements for PLC can be found in openly accessible sources. Even then, in most cases PLC is either considered as an alternative Telecom supplier or it is evaluated for broadband services such as Internet. Narrowband services are viewed for the most part as infrastructure upgrades and not necessarily evaluated as revenue generating services themselves.

Costs for PLC service development/implementation are generally subdivided according to the following aspects:

- Access Investment
- Home Automation Investment
- Operational Cost

Most access investment literature deal with the telecommunications infrastructure. Eikelmann [2], Whittaker [3], and Fröroth [4] all mention figures between US$ 500 - 800 as being the investment per customer, depending on population density and degree of penetration. These figures do not include home automation investments made inside the home. Services would be limited to typical telecommunication services such as telephone, Internet, video on demand, etc.

Most home automation as exists today is not based on PLC. Stadswonen [5] calculates customer investment cost of US$ 1500 for home automation including infrastructure costs like special wiring. This cost is reduced when applied in newly built residences. PLC-based home automation should cost less since the infrastructure (wiring) is already in place. The ASCOM PassPort PC network [6] for example can be delivered starting at US$ 60.

In order to connect the last mile to home access for in-home ‘smart’ application networks, it is necessary to install a building concentrator similar to ones used using telecommunication solutions. This 'last mile' infrastructure is one of the strengths of PLC since much of the in-home intelligence can be implemented outside of the house near the substation. Thus investments in concentrators and similar equipment would be made to the benefit of a potentially larger group of customers, per installation, instead of to the benefit of one home, as with telecommunication solutions.

Operational costs depend largely on the type of services offered. We have found no literature giving insight to any real operational-service cost relationships. Cost figures in the telecommunications market are also protected or not published.

Below, we provide reviews of frameworks for understanding cost elements for PLC infrastructures and services and some preliminary evaluations of PLC viability.

7.2.4.1 Booz, Allen & Hamilton

Eikelmann [2] (Booz, Allen & Hamilton) sets a framework for a financial evaluation of PLC access/provider models. He divides the infrastructure in three parts: a local access provider, an extended access provider to gain access to the telco access network, and a city carrier in order to switch to the telco backbone.

	Revenue Parameters	Cost Parameters
PLC Access Provider	• Fixed access fee per connected customer • Revenue dependent on number of carriers served	• Investment in low voltage access network upgrade and customer premise connection (hw) • Operations and maintenance cost
Extended Access Provider	• Fixed access fee for centralised access • Additional revenue stream from data services (e.g. high speed Internet) • Revenue dependent on number of carriers served	• Investment in low voltage network upgrade and telco access network • Operations and maintenance cost for both low voltage and telco access network
City Carrier	• All local telecommunications and data services • Interconnection revenue for long distance call termination	• Investment in complete local access network and switching equipment • Local network operation and maintenance • Service providing costs • Variable interconnection costs

Table 1. Key revenue and cost parameters of a PLC business case

The types of PLC services delivered depend on the access/provider model provided. Centralised home automation requires a PLC access provider. On the other hand, fully integrated telecommunications services require a city carrier as well.

Eikelmann gives a cost estimate based on 1 Mbps bandwidth full Internet access and telephony:
Deployment Costs:
Customer Premises Equipment (1 per premise)

- network interface: 300 US$
- coupler: 20 US$

Base station (1 per 20 premises): 3500 US$
Main station (1 per 7200 premises): 100,000 US$
Total per premise: 715 US$

Eikelmann concludes that PLC is only attractive in high-density urban areas with high spending telecommunication customers, given the investment costs associated with full access.

7.2.4.2 ABN/AMRO

Land [7] (ABN/AMRO) also considers the case of PLC as an alternative telecommunications operator. Cost *factors* have been identified, but Land gives no indication of cost *figures*.

Revenue forecasting can be practised along two lines:

- Topdown: Market segment value growth: voice, data, …
  Customer segment value growth: corporations, sme's, …
  Forecast second operator market share
- Bottom-up: Detailed analysis of customer base by contract value
  Second operator's ability to reach the customer

OPERATING COSTS	CAPITAL EXPENDITURE
- Way/leave access payment	- trunk network cables
- universal service fund contribution	- transmission mechanism
- leased lines	- switches
- network maintenance	- routers
- IT systems	- local access (fixed / wireless)
- billing / administration	- network management centre
- sales / marketing	
- bad debt	

Table 2. Operating costs and investments for PLC

7.2.4.3 Vattenfall / KTH

Fröroth [4] (Vattenfall / KTH) sketches the access network alternatives for broadband access to residential customers and compares the different commercially available alternatives including low voltage powerline. The topology of PLC is based on substations near the customer as implemented in Sweden.

These conclusions are applicable in Europe and several Asian countries. Investments per customer depend on the population density of the domestic area. Also the degree of penetration (percentage of customers reached in each area) is a main factor. Fröroth gives the following preliminary figures on investment per new customer:

	customers / substation	*degree of penetration* 20%	*50%*	*80%*
urban area	200 - 900	€ 508	€ 552	€ 415
suburban area	20 - 200	€ 813	€ 727	€ 583
rural area	1 - 20	powerline not feasible		

Table 3. Investment per new customer

These estimates are consistent with those of Booze, Allen & Hamilton given above. Investments consist of substation communication hardware, substation filters, network filters and customer filters and customer communication hardware. Itemized cost figures, as given by Fröroth, are shown in the Tables below, for metropolitan and suburb areas, respectively. The deployment stages in these tables are based on customer coverage in the denoted area. Costs are cumulative from stage 1 to stage 2 to stage 3.

Itemised cost, Euro, per stage	**Stage 1**	**Stage 2**	**Stage 3**
Built-out ratio	**20%**	**50%**	**80%**
Customers per km^2	325	812	1300
Substation comm hardware	75,000	75,000	75,000
Substation filters	25,000	0	0
Network filters	0	15,000	30,000

Customer filters (all sites) Customer comm hardware	0 65,000	81,300 97,400	0 97,600
Investment per km^2	**165,000**	**268,700**	**202,600**
Investment per new customer	508	552	415

Table 4. Itemized cost, in EUR, per stage, for metropolitan area

Itemised cost, Euro, per stage	Stage 1	Stage 2	Stage 3
Built-out ratio Customers per km^2	**20%** 31	**50%** 77	**80%** 124
Substation comm hardware Substation filters Network filters	15,000 4,000 0	15,000 0 1,000	15,000 0 3,000
Customer filters (all sites) Customer comm hardware	0 6,200	7,800 9,200	0 9,400
Investment per km^2	**25,200**	**33,500**	**27,400**
Investment per new customer	813	727	583

Table 5. Itemized cost, in EUR, per stage, for suburban area

7.2.4.4 Grey Hairs

Boon [8] (Grey Hairs) discusses the competitive elements for Electricity Companies competing on the Telecom Market. Like Eikelmann, he concentrates on broadband telecommunication services. Based on cost analysis he concludes that the substitution market is fierce. PLC has a lower capital cost advantage *only* in supplementary markets where competitors face new investments. Growth in this market might provide opportunity. Local access monopoly is difficult to break open. Access suppliers have a lead start: they can 'compete for the customer instead of for the call.'

7.2.4.5 NOR.WEB

Richards [9] (NOR.WEB) defines critical success factors for PLC broadband (1 Mbps) services to residential and business subscribers. He states that there are three main factors: cost, cost, cost. He distinguishes the following three cost factors:

- Accessibility-cost
  Accessibility of service refers to service reach. From the customer's perspective, time to log-on is vital, cost is based on sign-on charges, monthly tariffs, usage charges, and equipment purchases. This kind of service requires flat monthly tariff or even free access to be paid by merchants / advertisers.
- Applicability-cost
  Applicability of service refers to the support of the type of application the user wants or needs. Main issues are speed, reliability and ease of use. Limited bandwidth leads to higher costs. PLC could provide a cost-competitive solution here.
- Acceptability-cost
  Acceptability of service refers to the value and performance of service, the support and its effectiveness.

Richards concludes that the low voltage PLC more than competes with alternatives like cable and ISDN/ADSL in mass access for Datacom services: "Powerline is about ten times faster than ISDN, at about half the cost." The article was written however before NOR.WEB closed, and apparently some of the performance estimates were premature for NOR.WEB.

7.2.4.6 Cambridge Consultants

Whittaker & Hay [3] (Cambridge Consultants) offer cost figures on investment for PLC services:

- Filter termination units add cost per the number of homes passed: 70 US$, consisting of 40 US$ for components and manufacture and 20 - 30 US$ for installation. At 10 % penetration this leads to 700 US$ per home connected.
- Electromagnetic compatibility constraints lead to cost for DSP in the modem. For ADSL, Whittaker gives a cost figure of 320 - 500 US$.
- Substation equipment leads to the following cost factors: Re-cabling to the substation at 100 US$ per trench meter. 1 base station at each substation including a robust outdoor cabinet costs 20-25 US$. At 10 % penetration and 200 homes per substation this leads to 1100 US$ per user.
- Costs may be reduced in short- to medium-term, such that 500 substations could be covered for 25 US$ per home passed, leading to 250 US$ per customer (10% penetration).

7.2.4.7 CSC Consulting

Alvord [10] (CSC Consulting, today AMS) takes a closer look at narrowband service cost parameters and profit potentials. He concludes the value of residential DSM to be at least 500 - 600 US$ per home per year, based on the following drivers:

- Retaining old and getting new customers - the value of a customer to a utility is 3000 US$, the profit per customer is often over 200 US$ per year.
- Shifting residential loads to off-peak times - EPRI and EEI studies indicate up to15% generation efficiency, which could lead to 200 - 300 US$ per home per year.
- More efficient, better customer service operations with interactive link to the customer lead to (unspecified) lower costs.
- Elimination of manual meter reading costs lead to cost savings of 6 - 18 US$ per customer per year.
- Deferred plant, transmission, and distribution construction due to lowering the overall peak need (load profiling) can contribute significantly to lower costs over the long-term.

Revenue related to non-energy management (home security, Internet, *e*-business, video-on-demand, telephone services, etc.) will contribute to the customer value. Alvord calls the energy gateway a Trojan Horse.

7.2.4.8 The Intelogis PassPort Network

In-home network services have been identified as a potential service of interest for PLC providers. The following description of an existing product offers insight to the potentials and additional costs associated with present in-home networking solutions. (From http://www.businessweek.com/1999/99_46/b3655047.htm)
"The Intelogis PassPort [11] network kit ($180) uses AC electric wiring in the walls to send data from one PC to another. It's incredibly easy to connect: You plug

modules that resemble oversized bars of Ivory soap into wall sockets, and link them via six-foot cables to the printer ports on your PCs. This time what tripped me up was my house. An Edwardian-era flat, it has few wall sockets--a problem because PassPort must be plugged into the wall, not into power strips. So each computer must be within six feet or so of a wall socket. To test PassPort, I had to put my desktop PC on the floor of my study, the printer on a chair in the dining room, and the laptop on my bedroom dresser. So much for convenience. The good news? It worked. I could call up files on my laptop hard drive from my desktop PC. When I told my PC to print a document, the sound of the printer kicking into gear in the next room provoked near-elation. I ate dinner with glee."

This signals a warning that PLC solutions in practice are not always as good as promised. It should be noted that the Intelogis PassPort was the only working product. The reporter was unable to install two alternatives, using wireless and telephone lines. Note: The Intelogis catalogue on Internet mentions a price of $60 for the PassPort Network Starter Kit, connecting 2 PCs and one printer.

7.2.4.9 ASCOM Technical Solution

"We at ASCOM link the communications world into your power socket !"
ASCOM has developed a technical solution for PLC including the last mile home access [6]. At the moment they are planning field tests in Europe.

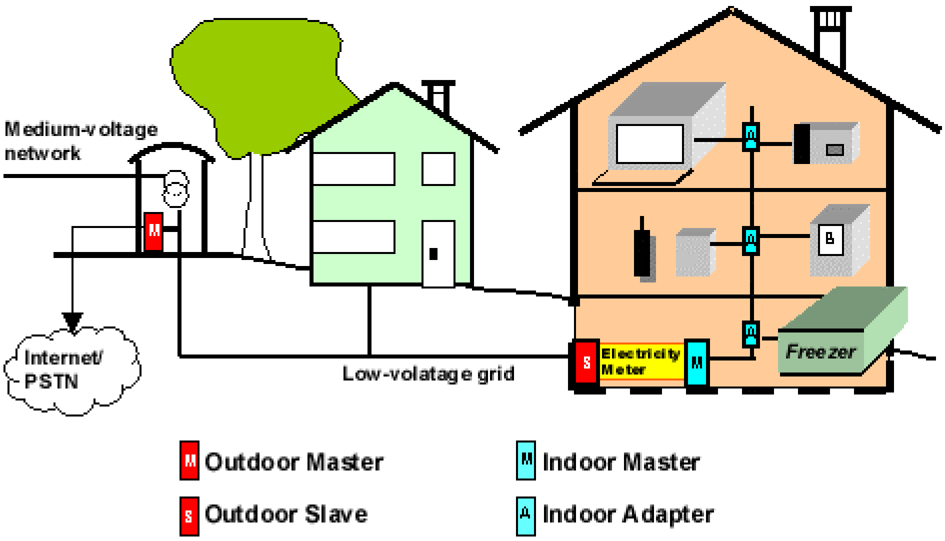

Figure 1. The ASCOM powerline solution

The ASCOM Outdoor Master has a connection capacity of ± 250 homes. ASCOM claims that it has an economically viable roll-out from 5% of 250 homes to 5 % of 150 homes. The Outdoor Slave has to be installed before or after the electricity meter. It could be placed in the same housing as the Indoor Master when placed before the electricity meter. The Indoor Adapter comes in two versions - broadband and narrowband - with standard interfaces for CPEs (Customer Premises Equipment). In a later phase direct integration to PCs and household machines is planned.

7.2.4.10 Stadswonen - Comfort ID

According to Stadswonen [5], a company in The Netherlands that integrates home automation in rental apartments in an urban environment, the total extra investment in home automation per home is in the order of US$ 1500.

The Smart Home Foundation in The Netherlands also mentions a figure of 1500 EUR as the total price per apartment for the implementation of a smart home system in a project in Zwijndrecht (Belgium), including safety & security and basic energy and comfort optimization
(http://www.smart-homes.nl/engels/smarthome.html).

The Comfort ID system of Stadswonen controls comfort, convenience, efficiency, security and reliability in homes and small offices. The following main functionality is implemented:

- comfort, convenience, efficiency, security and reliable;
- centralised energy management including energy purchase, maintenance and billing;
- intelligent control of heating, hot water, ventilation, adapted to individual desire;
- automated fault detection and handling;
- automated control of lighting, sunblinds, security.

No information is given on the operational and maintenance cost of the system.

7.2.4.11 Coactive Networks

Coactive Networks [12], [13] describe in their brochures the following types of services:

Service	Investment (incl. installation) by utility	Investment (incl. installation) by user	Monthly revenue for service provider
• Communications	240 $		10 $
• Appliance Control		90 $	5 $
• Family Messaging		40 $	5 $
• Security		260 $	5 $
• Home Care		350 $	10 $
• Metering	95 $		1 $
• Energy Management	100 $		2 $

These services are to be delivered by the Coactive Residential Gateway. This gateway provides local intelligence, is able to connect different Internet access networks to multiple types of in-home networks and can deliver different e-services over one single connection.

Coactive Networks has developed a business model involving four market parties:
- Network Provider, delivering infrastructure and optional e-services,
- Service Provider,
- End User,
- Data Consumer, any party interested in telemetry data from end user.

Four deployment scenarios (provided in [13]) with different degrees of penetration for varying service packages show return on investment between 12 and 21 months.

7.2.4.12 Sensel / Vattenfall

Within the coming months a large project in Sweden will be set up by Sensel AB, a subsidiary of Vattenfall, to provide more than 500000 homes with a Sensel Box, using the Coactive Network residential gateway, to roll out smart home services. Sensel [14] considers itself as an 'intelligent service operator'. They will invest in the infrastructure and create a platform for other service providers to offer their services. They also plan to operate, maintain and host these services. As a starting point Sensel and Vattenfall will use the infrastructure for remote meter reading. Other services will be offered either by Vattenfall, or by any service provider willing to use this intelligent infrastructure (and pay for it).

7.2.4.13 Parks Associates

Parks Associates [15] gives an overview of a number of residential gateways, including Coactive and emWare. Other gateways are coming from: 2Wire Inc, Sharegate, Cayman, Cisco, Sage, Emerald, SmartAmerica, Panja, Philips. Functionality ranges from telecommunications, Internet and video to metering, load control and home automation. Prices vary widely from hundreds of dollars to several thousands. The gateway should have the following functionalities:
- seamless integration with existing home systems and electronic devices,
- provision for future home services,
- create surplus value for both consumers and service provider(s),
- terminate all external networks,
- allow different means of distribution and installation.

Broadband applications are seen as the main driver for development of the residential gateway (Internet: shared and high-speed; distributed video). Intelligent management, especially. energy management and home control) are considered useful spin-offs. The willingness to adopt the residential gateway is positive as long as the costs are lower than US$ 250 (70 %).

7.2.5 Customer Equity

Recently several Internet Providers have been introduced on the national and international stock exchanges. Their market-value can give an indication of the value of their customer base. Calculations for market leaders like Freeserve (Great Britain), Terra Networks (Spain), T-Online (Germany), World Online and UPC (The Netherlands) lead to varying figures between US$ 1000 and US$ 10000 and even higher. These figures are not likely sustainable. However, competition for becoming the access portal for the customer has never been more fierce and is based mainly on very basic services. Profitability of most ISP services and portals remains lower (with the exception of America Online) than traditional relationships of profits to stock values, and apparently company market values are based on discounted expected cashflows of revenue streams (and profits) from services as yet to be developed.

Cable Internet tariffs in the Netherlands vary from 25 - 40 US$/month (flat-rate) with free data traffic restricted to several 200 - 500 Mb/month. This tariff is expected to decrease. Telephone Internet tariffs in the Netherlands are in many cases limited to the telephone ticks. No flat rate is being paid unless a customer requires extra services. Up to less than one year ago the monthly flat rate was 10 - 15 US$. Telephone companies are paying ISP's for ticks generated.

7.2.6 Summary

This chapter reviewed a dynamic market and service model perspective on operational customer service and costs associated with PLC services in deregulating power markets. Long-term administrative and equipment costs and changes in customer service models for PLC services can only be speculated upon since many of these services do not yet exist in the electrical industry. The telecommunication businesses such as fixed wire telephony- and mobile-services were analysed as precursors to help us understand the relationship between market dynamics and its influence on service, billing, and business models for PLC services. We also provided a literature survey, which gives some detail about projected costs related to PLC deployment.

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8 European projects related to the PALAS project

René Kamphuis (ECN)

8.1 ESPRIT projects

A number of projects have been carried out from 1990 onwards with EU-funding in the EHS-consortium (www.ehsa.com gives a detailed overview of EHS-projects and companies). This European Home System consortium has defined and built a "bus"-architecture and communication protocols to establish communication between appliances and a central processing unit in homes. This central processing unit can be part of or evolve to a domestic gateway with a last-mile interconnection to service providers and from that point of view is of interest to PALAS. Physical layers were implemented for the powerline, twisted pair and wireless communications. Furthermore an IAI (Intelligent Appliance Interface) was designed in this project. Follow-up of EHS is the CONVERGENCE initiative, which aims at reducing the cost of EHS-components to 140 Euro for a complete system.

In the EU-ESPRIT EHS-initiative a number of projects were finished:

- In the HSComponents project (ESPRIT 6782) a number of components were build for usage in homes. One of the components included a power line modem. In the CHABLIS-project (Consumer Home Appliances on Low-cost Intelligent Sockets; ESPRIT 24081)) the focus is on making the socket intelligent. Aims in this project were: replacing fixed Ampere fuses with dynamically real-time adaptable configurations also usable in load-management applications and the creation of entries on a mass-market.
- In the OSIM-AHS project (Open Scalable and Intelligent Meter for Advanced Home Systems; ESPRIT 9264) An intelligent meter prototype was designed and built with a two-way communication mechanism to the utility
- In the ETHOS-project energy and tariff-management field tests in four countries were executed using the EHS-technology. Participants in this project were EDF, UK Eastern Electricity and ENEL among others. By a two-way communication mechanism, DSM (Demand Side Management) strategies are implemented for handling tariff-structures and energy management by utility companies. In certain countries in the EU there is a large difference in tariff for individual households if a certain maximum value is superceded. For instance, in Italy switching from 3 Kwt to 6 Kwt contracts is very expensive and can be avoided by using intelligent appliances. Adding microprocessor intelligence and network connectivity to gas based appliances to optimize the heating performance in dwellings is the purpose of the GAP-project (ESPRIT 21667). In the DICE-project (Demonstrate Integration if Components for Energy applications) an electric water heater is selected as a widely used appliance to instrument with EHS. Using smart control and connectivity to the electricity supplier energy efficiency savings were demonstrated.
- In the HomeNet project (ESPRIT 22937) interconnection and integration of narrow-band control via EHS and broadband media is the main research item. A TV user interface controlling the home appliances was one of the research items.

- In the ELECLine-project (ESPRIT 21314) a complete system for household appliances communicating via power line with an energy management and information system is the research focus. In this project a Cable TV gateway is defined for connection to a service provider.

8.2 IST fifth framework projects

Some projects in IST (www.cordis.lu/ist gives the list of current projects) have recently been started.
In the SIRLAN-project (Secured Infrastructure for Commercial and Residential Buildings Local Area Networks; IST-1999-12295) a toolkit platform is established for in-house and outside communication through any kind of communication network. The platform will be used to define new products and to develop new services. In this project the CONVERGENCE-standard defines the hardware and protocols.

In the INHOMNET (IN HOMe high-speed NETwork; IST-1999-10523) broadband-distribution of multimedia content via IEEE 1394 is the research focus. Digital in-house technology will enable new services, applications and communication infra-structures. The project researches new kinds of networking with high data throughput and reliability for transmitting streaming digital audio video and control data. New interfaces, user software and related middleware will be developed in this project. IEEE-1394 networking is the basic technology for the project. In the MYTV-project (Personalized services for digital television; IST-1999-11702) and CORENET (Context organising user interfaces for networked home applications; IST 1999-19994) similar small-scale broadband distribution research focuses are chosen.

Last-mile access technology and service development is the research item in the projects HAS VIDEO BOX (IST-1999-11719), WINE (Wireles Access Networks; IST-1999-10028), NG-DSL (Next Generation Digital Subscriber Line algorithm and architecture development; IST-1999-19996) and HARMONICS (Hybrid Access Reconfigurable Multi-wavelength Optical Networks for IP-based Communication Services; IST-1999-11719). These projects have access to end users using different transmission media as their research objective.

In the NETGATE (Advanced Network Adapter for the new Generation of mobile and IP based Networks; IST-1999-10905) a wireless gateway to IP based networks is a research issue. The NETGATE project aims at delivering a low-cost, high performance gateway with a large degree of interoperability between several transportmedia..

Developing tools for services are research items in OCCAMM (Open Components for Controlled Access; IST-1999-11443). The OCCAMM project addresses the problem of open architectures and interfaces for on-line access to digital content with IPR protection and management, seen as an evolutionary process from today's piecemeal initiatives to full-fledged multimedia. Trials will be conducted with this facility, involving real end-users both in the home and in schools, to validate innovative business models for the benefit of market operators.

9 An outlook on PLC development for Electronic Power Markets and Utility e-business

Hans Ottosson and Fredrik Ygge (EnerSearch), and Hans Akkermans (AKMC)

One large area, not much exposed yet, is the possibility to use PowerLine Communication for what can be regarded as ***"utility core operations services"*** - in principle *narrow-band* technologies (kBps). The intention of this Chapter is to give an outlook toward this sector for services, where the utilities themselves are the customers.

The discussed services are characterized by:

- a high degree of innovation, in which advanced computer technology is introduced.
- a high reliability, since proven PLC technology is used within the regulated frequency band.
- a low risk factor, since the complete value chain rests within the utility.
- a high degree of interest, since the services are directly related to the utility core business.

Examples of such core utility services are: efficient management of energy distribution, on-line control for maintenance, remote observation for grid control, fine-grained automated load management and resource allocation on the distribution level, electronic power markets, and other forms of (networked) utility e-business.

The industrial trend today is to distribute microprocessor capacity and increase distributed intelligence in many sectors. PLC is for the utility industry branch a most attractive way of bringing communication to and in between components and functions to support efficient distribution of electricity.

The necessity to develop new tools for grid management is related to the new environment of the deregulated energy sector. In many cases, utilities are decreasing the number of dispatch and control centers. In critical situations, it is foreseen that utilities have to operate regional grids as separate systems. In this mode of operation, the possibility to introduce intelligence into the energy value chain is vital.

The PALAS project focuses on the use of the power grid as an access network. For utility operations services, the power grid is the infrastructure best suited for communication access to the components and functions needed for those services.

The intention of this outlook is to show to the reader the new utility application area for PLC technology. Studies are proposed related to both the Technical Framework and the Service Framework of the PALAS project, as a complement to the other work being done within the project. During the time frame covered by the PALAS project (2000-2001), practical investigations and field tests are proposed to be performed in a distribution grid in Sweden as one of the PALAS trials.

9.1 Background

Electric power networks have long been recognized as being critical infrastructures of industrialized nations. In modern times, two other networks have also become critical in this sense: communication networks and computer networks. Communication systems and computers have become indispensable in everyday life – from commercial enterprises to entertainment industries – and it is difficult to imagine a life without the amenities that these systems offer. Traditionally, electric power networks have used the computer and communication networks in a variety of critical applications. However, there are exciting possibilities to invent new configurations and organizations of power, communication and computer networks in such a way that they would be more robust in the face of catastrophes, and could be better controlled and protected for optimum security, economy, and performance.

The powerline has outstanding features that make it highly feasible for utility communication purposes, because it is always connected to every needed component and process within the distribution grid.

Efficient energy management is economically important in a deregulated power market and one of the most important, if not the most important, environmental issue. Utility core operations services aim at developing and implementing new means for energy management based on modern ICT, in which PowerLine Communication plays an important and vital role.

The societal call for higher environmental concern, as well as the increased competition in the energy sector, together with the technological development in the computation as well the communication areas (e.g. in the area of power line communication) makes the research and application area expansive and dynamic.

The work will provide knowledge to the energy-related industry and to the information society sector on the possibilities to make the energy systems more efficient (from monetary as well as from environmental and technical perspectives) by the integration of information use and distributed intelligence into the energy chain. At the same time, universities will benefit from the close co-operation with key industrial players in the European and other international energy markets.

The over-all idea is to provide an intelligent transparent communication network through PowerLine Communication on top of which automated intelligent agent software technology may act in a number of applications.

9.2 Electronic Power Markets

The recently started Electronic Power Market (EPM) program focuses on the demand and energy management in distribution grids. It will be investigated if very fast electronic power markets can be utilized for managing the network in both normal and critical situations.

The main components in this work are:

- Economical models of customers on an EPM.
  - What are the most well suited loads for this operation?
  - How large are the customer incentives to participate in these type of activities?
- EPM from a system management point of view.
  - What types of control instruments would an EPM give to the system operator?
- Technical aspects of EPM.
  - How are EPMs designed from an algorithmic and information systems point of view?
  - Are EPMs feasible in critical situations?

The driving forces for the work are:

- The electricity prices vary over time, and particularly the short term (control or regulating) prices vary significantly.
- Competition is introduced in most energy markets.
- Many loads are not time critical, implying that demand can be shifted between different time periods with little inconvenience for the customer. The time frame in this respect may be on a minute scale.
- The price for global and local communication is decreasing while communication capacity increases.
- The price for local computational power is decreasing, and more and more devices are equipped with microcomputers.
- The demand for new tools for efficient control and distribution of electricity increases in both ordinary situations and at critical situations and disturbances.

Taking this all together, this motivates studies of: (1) new means to co-ordinate producers, distributors, and consumers of power, i.e., new electronic markets for power trade, and (2) efficient strategies for actors on current and future power markets.

The growth of the Internet has drastically increased the interest in and relevance of electronic commerce. There are already a number of electronic auction servers running on the Internet (such as the AuctionBot and eBay). Of particular interest is the possibility for real-world parties to be represented by trading software programs: software agents. The introduction of software agents enables new market mechanisms [1] [2] .

For example, when negotiating over a number of commodities, far more possibilities can be evaluated by software agents than by their human counterparts. Power markets are examples of such complex markets, because there are dependencies between the production at different time periods, and also between distribution and consumption. Furthermore, there are complex dependencies between the different actors. Electronic power markets can hence potentially increase the efficiency for all actors. They also allow for smaller consumers and producers to directly participate on the market, rather than buying through a reseller [3] .

9.3 Efficient Strategies for Power Market Actors

As prices of power vary significantly over time and as many loads are not time critical, there is an incentive to control loads at the consumer side. How to control the loads locally is tightly connected to how to act on an electronic power market [4] . Computational power is being integrated in more and more devices. Local and global communication capabilities are continuously increased. Even the extreme example of a software agent representing an "intelligent house" planning its power usage and buying the needed power directly from an electronic power market does not seem too far fetched [5] . In a shorter time frame, larger users – such as industries – are in focus. This reasoning also applies directly to smaller and larger producers.

The use of this type of load control is already in use to create "virtual gas turbines" and the like. The main improvement enabled by new technology is that these measures can be taken at a more fine grained level and be more automated, yielding higher efficiency.

The work can be divided into three main, highly inter-linked subjects:

- negotiation between self-interested (software) agents
- efficient algorithms for markets and distributed resource allocation
- the use of power-line communication as an interactive intelligent network.

The first subject deals with issues such as what the properties of different electronic market mechanisms are. Relevant properties include (economic) efficiency of the outcome, vulnerability to speculation (i.e. can an agent harm the outcome by giving "false" bids [6]), and computational demands on the participating agents (i.e. does the mechanism require very sophisticated agents in order to work well?). This subject requires challenging interdisciplinary research of an economics/computer science nature. The focus of the work related to this subject is on studies and development of mechanisms suitable for electronic power markets.

The second subject is more traditional from a computer science point of view; it deals with algorithmic aspects [7] . Even if a market protocol has very favorable (economics) theoretical properties, to compute the outcome may be computationally intractable. For example, it has recently been seen that combinatorial auctions in which bids can be placed on many items, despite its relatively simple nature, is computationally complex [8] . This essentially means that if the number of bids and commodities is significantly large, no known algorithm can determine an optimal winner combination in practical time. The corresponding holds for the internal optimization of e.g. an industry; even if all prices and all process characteristics are known with certainty, it may impossible to compute the optimal schedule. The focus of the work related to this subject is on computational analysis of different market mechanisms and the development of new (approximate and optimal) algorithms for the distributed market/resource allocation problems relevant to power management.

The third subject deals with the possibility to develop power-line communication as an interactive, always on-line intelligent network for advanced negotiations and resource allocations. During the time frame covered by the PALAS project (2000-

2001), practical investigations and field tests are proposed to be performed in a distribution grid in Sweden as one of the PALAS trials.

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10 Summary: The Potential of PLC Services

Hans Akkermans (AKMC) and *Hans Ottosson (EnerSearch)*

In this report we have identified and discussed three major categories of new services enabled by PowerLine Communication (PLC) technology: (1) broadband communication access; (2) in-home building services; (3) services to core utility operations.

10.1 PLC broadband communication services

PLC offers an alternative last mile access technology for broadband telecommunication services. Some of these services are well-known and their business case is therefore well established (e.g., telephony, IP data services). Other services (large-scale mobile communications, IP media content delivery) are now quickly being developed and rolled out on the basis of heavily competing access technologies of which PLC is one. The baseline services have been outlined in Chapter 5, and more advanced ones have been discussed in Chapter 6. Chapter 7 has put together available public source information on customer service and operational cost issues, while Chapter 3 has considered relevant frequency standards issues to be dealt with. Field trials as well as market studies in this area will be carried out in the further stages of the PALAS project.

10.2 Internet in-home and building management services

Another major innovative application area for PLC-based services concerns in-home IP networks in buildings, offices, and residential homes. This area is especially quickly developing in the USA and, to a lesser extent, Scandinavia. A wide range of next-generation Internet services for “intelligent” homes and buildings is envisioned here, ranging from automatic energy and building management, security applications, health and elderly care, and other information, communication, and control at-a-distance applications. Especially interesting for service providers is the opportunity here to combine access and in-home network capabilities for service and systems integration. Discussions and state of the art literature surveys are found in Chapters 6 and 7. Related European projects are surveyed in Chapter 8. Also in this area the PALAS project is planning to look at field trials and market studies.

10.3 e-Utility energy value chain operations

Third, a major application area for PLC-based innovation are the core business processes of the utility sector itself. Here we see that strong business interest (because it involves core utility operations and infrastructure asset management) already exists, together with a background of well-understood telemetry services (considered in Chapter 5). Moreover, the technological risks are limited as it mainly involves narrowband PLC requirements. However, due to the deregulation and liberalization of the sector, coupled to the Internet opportunities, the utility business landscape is changing drastically. Essentially, the energy value chain is being deconstructed and reorganized in different ways, similar to what we observe in other industrial e-business sectors. PLC can be a key technology to achieve this, and some of the future PALAS field trials focus on this area of the "e-utility". This is discussed in Chapter 9 of this report. Thus, PLC has the potential to bring the utility sector as a whole into the new era of Internet and electronic business.