Power Line Communications – Past Present and Future

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Abstract

This paper gives an overview of power line communications (PLC) and aims to touch upon some of the historical developments in power line systems and their subsequent applications. It focuses on some of the key technology drivers which have influenced development of PLC and more recently the development of broad band Power Line Telecommunications (PLT). The importance of standards development and the requirement to harmonise PLC systems with existing radio services is emphasised. The paper then goes on to consider some of the business drivers which have underpinned recent developments. In particular, the influence of the almost global liberalisation of the telecommunications market together with the unparalleled growth of digital services and the Internet.

Note: The author has made reference to 27 publications in order to provide a reasonably broad based information source for those who might wish to undertake further, more detailed, studies into PLC system and/or applications development.

Introduction

Perhaps 'necessity is the mother of invention' and power line communications is no exception. The ability to transmit information over an established, pervasive infrastructure such as a power distribution or transmission network has long been a goal. The idea of better controlling, measuring, maintaining, charging and receiving payment for the utility commodity, by use of the prime network, has a long history. The developments in computing and electronic hardware including packaging, size reduction and cost have also played a major part in forging the developments in power line communications coupled with the deregulation of the electricity utilities in many countries. More recently the almost global strive for the liberalisation of telecommunication services has added new dimensions to the potential applications of established wireline infrastructures including those of the incumbent telecommunication companies (TelCo's), particularly the local loop, originally designed to link telephones to the local telephone exchanges/offices. Furthermore, the birth and unparalleled growth of the Internet [1] and more recently Intranets [2] and Extranets [3] accelerates the demand for digital, telecommunication, access, services to almost every premise. Multimedia communications [4] are set to revolutionise the way we are informed, educated, entertained and employed. If such services can be carried over electricity distribution networks then a truly universal information superhighway might be realised, with the capability of providing interconnection to every school, university, home, factory and office [5].

Early history

As long ago as 1838 remote electricity supply metering was proposed by Edward Davy [6] for the purpose of checking the voltage levels of batteries at unmanned sites on the London – Liverpool telegraph system and in 1897 Joseph Routin and C E L Brown of Zurich, Switzerland took out British Patent No. 24833 on their powerline signalling electricity meter [7]. In 1905 Chester Thoradson of Chicago patented his system, devised in 1902 for the remote reading of electricity meters [8] using an additional signalling wire. The scheme was not taken up on a commercial basis because of insufficient cost benefit and the system was discontinued. In 1913, automatic electromechanical meter repeaters were produced and in 1927 the use of thermionic valves for metering was patented. In 1936 the indirectly heated cathode valve removed the need for batteries and in 1947 the miniature valve, followed in 1960 by the transistor, reduced the size considerably. By 1967 the integrated circuit and by 1980 the microprocessor was appearing, worldwide, in a variety of proposals. By the late 1980's and early 90's proposals for relatively sophisticated error control coding and their subsequent implementation onto low cost microcontollers within the hardware of a PLC modem were proposed [9].

Standards and Regulation

PLC standards have evolved over many years and continue to be further developed. In Europe the CENELEC band (3 kHz – 148.5 kHz, ref. EN50065) is currently allocated to classical narrow band PLC applications. The European standards bodies are detailed in Figure 1, with the BSI as a prime focus for the UK. Power Line Telecommunications (PLT) systems are now being developed [10] with data rates of several megabits per second. These systems operate over low voltage electricity distribution networks (LVEDN's) and are focused on providing commercially attractive broadband digital access solutions. Quite clearly future high data rate PLT will therefore be forced to penetrate into the higher frequency bands well above 148.5 kHz.

Therefore there is a considerable requirement to ensure that the standards and regulatory bodies are able to fast track the requirements of new technologies particularly those driven by developments such as the Internet where unprecedented rates of change are taking place. Indeed, the lack of fast access to the Internet is currently providing a *world wide wait*.

Also, the need to harmonise broadband wireline access technologies with existing radio services such that coexistence might be optimised, to the benefit of all, will be a key element in the rapid deployment of broadband PLT systems. The subject of EMC and broadband PLC applications, which propose to utilise sections of the HF bands, are now the focus of much detailed research [11].

Technology evolution

In order to understand the evolution of PLC we need to understand the evolution and growth of power distribution systems [12] and some of the basic facilities required to maintain and protect such systems. If we consider that the prime function of a power network is to distribute, in bulk, large amounts of electrical energy from a relatively small number of sources (the generators) to a relatively large number of sinks (customer appliances). The sources and sinks being distributed over large geographic areas. Then it obviously becomes important to protect sections of these networks in the event of fault conditions. Some of the first commercial 'power line carrier' applications were introduced [13] to provide protection facilities and indeed many such PLC systems are still in use today, particularly on overhead, high voltage (>36 kV), electricity transmission networks.

The philosophy behind their deployment included an appreciation of the fact that the transmission towers (pylons) were some of the most robust structures ever built and therefore from a reliability perspective any protection signalling would be best placed on such networks. It should be further designed to operate in a fail safe mode (e.g. unique addressing/polling/error detection/correction/handshaking). Additional functionality was introduced including point to point telephony to help engineers communicate between switching stations during complex switching operations. At the other end of the scale many systems were developed to control various types of load on the local, LVEDN's such as storage heaters, street lights and/or provide services such as remote meter reading [14] [15].

All of these PLC systems suffer a number of disadvantages and reliable power line communications has been the subject of significant research going back over 100 years. It was generally accepted that reliable communications with high data rates cannot be achieved because of the dynamic unpredictable nature of the power lines and the extreme noise levels and attenuation of such networks. The unpredictability of the network is such that a system can cease to operate at any time. The cause may be due to any change in the characteristics of the network such as the switching on or off of any appliance connected to the network, or indeed switching in additional sections of network. To minimise the effect of these changes, PLC systems have tended to use low frequency signalling coupled with very secure datagrams or packets of data, resulting in low data rates. There have been a number of detailed surveys undertaken which review the broader application of mains signalling systems, particularly in the UK [16] together with a number of papers which focus on certain niche markets such as remote meter reading [17] and customer service applications [18][19].

However, more recently research has focused on the behaviour of power networks at frequencies above 1 MHz. A particular emphasis has been placed on underground LVEDN's and a variety of digital, telecommunication, access, services have been demonstrated [20] [21] [22] [23].

The Internet, intranets and extranets the business drivers

Towards the end of September 1969, four US academic institutions – the University of Utah, the Stanford Research Institute, the University of California at Santa Barbara and at Los Angeles – were linked by an experimental computer network, ARPANET, funded by the Advanced Research Projects Agency (ARPA) of the US Department of Defence (DoD). With the benefit of a quarter of a century of hindsight this military-inspired development can now be seen as one of the seminal events in the history of communications. Out of the ARPANET has emerged the extraordinary phenomenon of the Internet – a computer network that already links tens of millions of users worldwide, while growing at a rate, that, unchecked, would cover the entire population of the earth by 2001 [1]. When the Internet was funded exclusively by government agencies, business use was understandably, subject to strict control. However, since the arrival of the public network operators at the end of the 1980's these constraints have effectively disappeared. Business use of the Internet is now booming, with over 70% of all new Internet subscriptions coming from companies.

As well as straightforward intra-company communication, businesses are increasingly exploiting the Internet as a means of exchanging information with customers, suppliers and business allies. The progressive utilities are also targeting new methods of on-line, interactive, customer service and customer billing applications [24] [25]. US analyst Killen & Associates is predicting that the Internet – as a medium for trade – a virtual marketplace where customers can order goods, then pay by utilising some form of electronic money will be worth £30 billion by 2005.

The potential business attraction of the Internet to the utility perhaps stems from the fact that most utilities and other large national and multinational organisations already have their own internets or corporate intranets [26]. The data networks already exists within these organisations and by adopting the use of open standards, primarily developed for the Internet, in their internal architectures universal communications becomes a possibility. With the advantages of open standards coupled with the wider bandwidth available on corporate network intranets, it becomes clear why intranets are becoming an enabling technology in their own right. To summarise, intranets provide:

- Cross-platform functionality
- A consistent view of information
- An enabling technology path
- Ease of integration
- Ease of communication
- Relatively low-cost installation
- Increased effectiveness of information

A huge area of potential growth is the extended intranet or extranet. The extranet provides business partners or individuals from different departments with defined access rights to each other's services in a virtual private network, separated from the Internet. Utilities might also exploit extranets targeted specifically at customer services or customer groups.

The missing and vital link in such networks is the local access to the customer. Until this is achieved then we have a world wide web which is restricted by a world wide wait for broadband access service capability. Digital PowerLine technology is poised to remove the world wide wait.

The future

It has been clearly demonstrated that PLC and more recently PLT, provided over LVEDN's, has enabled a means of cellular reuse of spectrum that would otherwise not be possible. Claude Shannon indicated how we might communicate in the presence of noise [27] and produced two theorems of profound significance to engineers who will further research PLT:

Theorem 1: *If a function f(t) contains no frequencies higher than W cps, it is completely determined by giving its ordinates at a series of points spaced 1/2W seconds apart.*

Theorem 2: *Let P be the average transmitter power, and suppose the noise is white thermal noise of power N in the band W. By sufficiently complicated encoding systems it is possible to transmit binary digits at a rate*

$$C = W \log_2 [(P+N)/N] \quad \ldots\ldots\ldots (1)$$

With as small a frequency of errors as desired. It is not possible by any encoding method to send at a higher rate and have an arbitrarily low frequency of errors.

NOR.WEB has demonstrated, in pilot trials in Europe, that underground, LVEDN's can deliver a nominal 1 Mb/s, digital, access services to the school, home and office, repeatedly, reliably, cost effectively and competitively. Whilst history shows us 'we never take any notice of history', we might take some comfort in the general observation that information technology based, business solutions which have good technical and commercial foundations, fulfil government policy, provide competition, meet potential customer needs on a global scale, extend the use of the electromagnetic spectrum and provide enhanced applications for electricity distribution networks are rarely , if ever, dismissed.

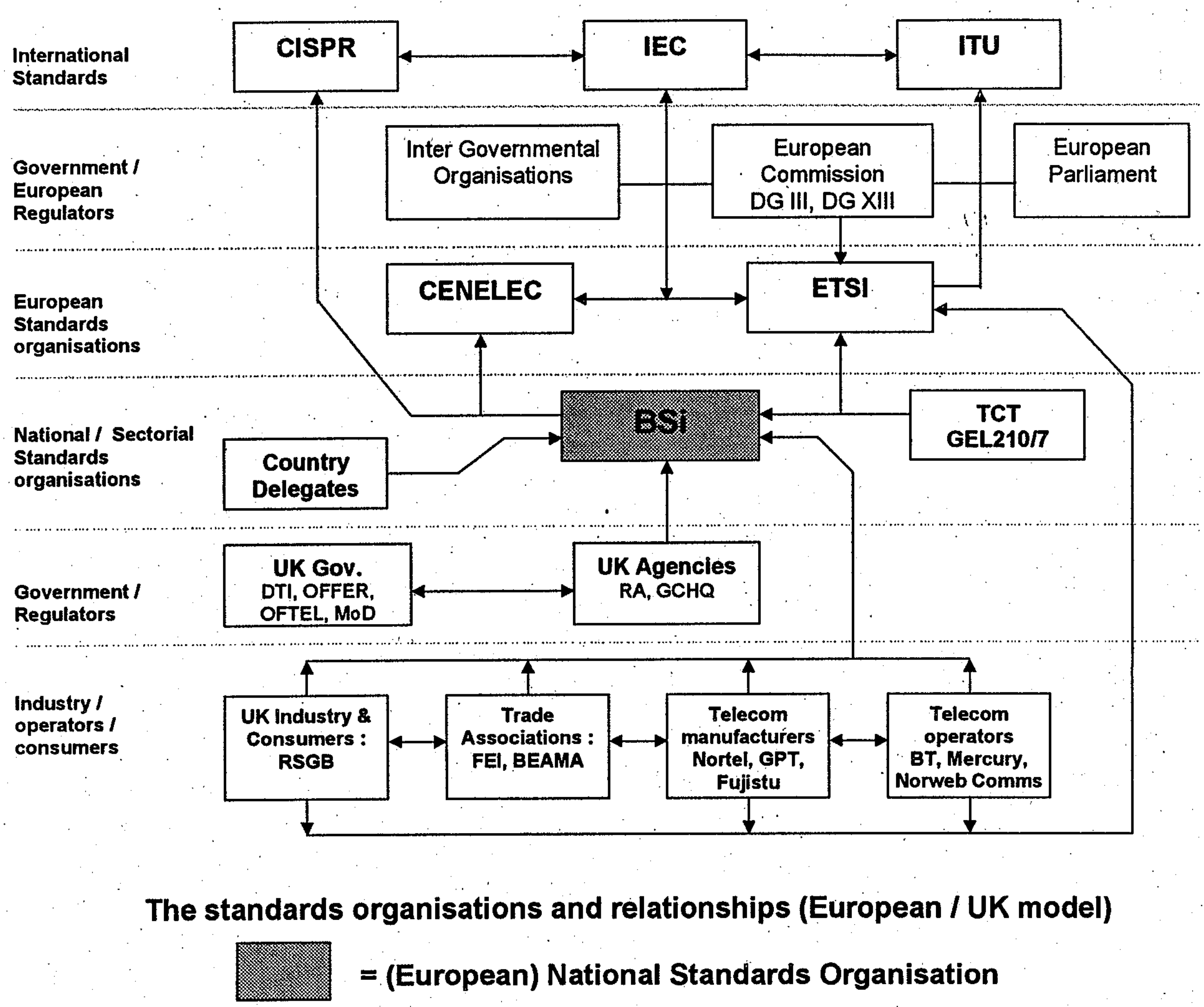

Figure 1

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About the Author

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Paul Brown is Director of Power Systems with NOR.WEB DPL Ltd the new joint venture company formed between Nortel (Northern Telecom) and United Utilities to market and develop Digital PowerLine (DPL) communication solutions worldwide. His current research activities focus on power network communication interfaces, combined local access architectures and multimedia platform development. He is also responsible for the maintenance and development of NOR.WEB's intellectual property portfolio, regulatory issues and the development of powerline communication standards.

His Power Systems Group has close links with the Universities of Lancaster and Salford. Joint research projects are currently underway with both universities and currently Paul Brown is an Honorary Professor in Communications Research at Lancaster. EPSRC funding has also been awarded under the 'Multimedia and Networking Applications Programme' for collaborative research projects with the Universities of Lancaster and Salford.

Prior to his present appointment Paul Brown was Research and Development Manager with NORWEB Communications.