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New Applications Using PLCs in Access Networks

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1. Introduction

Access Networks in telecommunications, such as digital subscriber lines (DSL) and wireless broadband networks (WBN) have become so popular that these systems are now found in almost all regions. The widespread use of these systems has brought about the need for research into new ways of resolving, or at the very least, minimizing the impact of problems that affect the performance of these systems.

In terms of DSL systems, crosstalk is one of the main performance limiting factors, principally when operating at high frequencies, as is the case with VDSL (very-high-bit-rate DSL) networks. Consequently, the required high data rates of VDSL systems may not be achievable if crosstalk levels are excessive.

Across WBN systems, the existence of co-channel interference increases the system's noise levels and also degrades the network's overall performance. It may be impossible therefore, depending on the noise level, to get even minimum system access. It is therefore necessary to plan a way of controlling these noise levels across both access networks.

Programmable logic controllers (PLCs) are the main types of controllers used within the industry. One of their characteristics is the fact that they can operate within aggressive environments (for example, at high temperatures or within high humidity levels) as well as having high operational speeds in comparison with corresponding electro-mechanic control systems; the PLC becoming a highly efficient control device with multiple usage possibilities.

Hence, the use of PLCs across access networks opens up additional fields of application for this type of device, especially due to the fact that up until now, the PLC's widest form of use has been in the industrial sector. Additionally, the robustness, flexibility and speed of the PLC allows it to be used across access networks without any additional need for major configuration changes to already installed equipment, i.e.; the implementation of a PLC into a system does not generate excessive costs or require excessively specialized configurations.

PLC application will focus on automated configurations in order to reduce system noise on access networks (DSL and WBN) with the intention of making sure the performance levels of these systems are not degraded in any way and are also able to operate within the expected performance parameters.

In this chapter, we propose alternative PLC applications on two types of broadband networks. Basic concepts about DSL networks and wireless broadband networks are presented in section 2. In section 3 the application of PLC on broadband networks is discussed. Final comments are presented in section 4.

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2. Access networks

2.1 DSL networks

DSL access technologies have been developed by the telephone companies to provide high-speed data rates over regular telephone wires. The term DSL covers a number of similar yet competing forms of DSL; including ADSL (asymmetric DSL), SHDSL (single-pair high speed DSL) and VDSL (Starr et al., 1999). These types of DSLs can be summarized as shown in Table 1 (Gonzalez, 2008).

Technology	Name	Ratified	Maximum speed capabilities
ADSL	Asymmetric Digital Subscriber Line, G.dmt	1999	6 Mbps (downstream) 800 kbps (upstream)
ADSL2	G.dmt.bis	2002	8 Mbps (downstream) 1 Mbps (upstream)
ADSL2+	ADSL2plus	2003	24 Mbps (downstream) 1 Mbps (upstream)
ADSL2-RE	Reach Extended	2003	8 Mbps (downstream) 1 Mbps (upstream)
SHDSL	Symmetric High-Bit Rate DSL	2003	5.6 Mbps (downstream/upstream)
VDSL1	Very-high-data-rate DSL 1	2004	55 Mbps (downstream) 15 Mbps (upstream)
VDSL2 -12 MHz long reach	VDSL 2	2005	55 Mbps (downstream) 30 Mbps (upstream)
VDSL2 - 30 MHz short reach	VDSL 2	2005	100 Mbps (downstream/upstream)

Table 1. DSL technology options

Some authors (Ödling et al., 2009) indicate a fourth broadband generation concept with data rates from around 100 Mbps to around 1 Gbps. In this case, broadband systems will operate on the twisted-copper pairs of the public telephone and fiber optic networks, namely DLS systems and fiber access systems.

Since DSL use relatively high spectrum frequencies, its signal is susceptible to external noise sources. Thus, the research into new ways of reducing noise impact on network performance are extremely useful in terms of design of well established DSL systems (ADSL, ADSL2+) as well as in relation to latest generation (VDSL1, VDSL2) networks.

Crosstalk is the electromagnetic coupling that occurs when electrical signals are transmitted over telephone wires. It is the main factor limiting the bit rate and the distances that can be achieved on DSL systems. A pair of individually insulated twisted together conductors has been designed to reduce this coupling and to improve system performance. The reason for this is due to a sufficiently short space between twists - the electromagnetic coupling of energy over a small segment of wire is canceled by the out-of-phase energy coupled on the next segment of wire (Starr et al., 1999).

There are two kinds of crosstalk: Next (near-end crosstalk) and Fext (far-end crosstalk). Next is the main obstacle for systems that share the same upstream and downstream frequency band. Next is the noise that appears on the other pair but at the same end of the cable as the source of interference (Cook et al., 1999), as shown in Fig. 1.

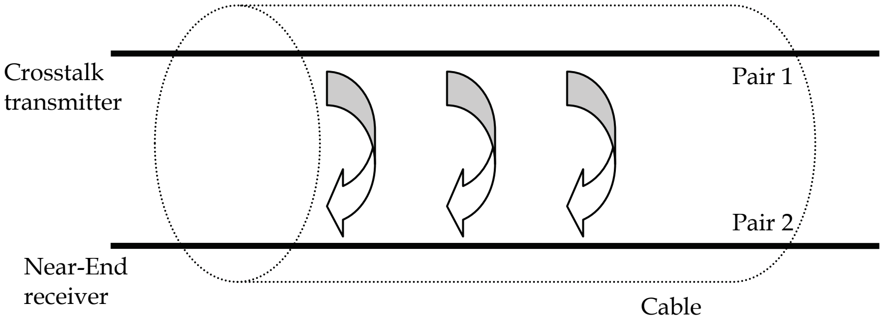


Fig. 1. Illustration of Next

Fext is the noise that appears on another pair, but at the opposite or far end of the cable to the source of noise (Cook et al., 1999). Fext is less harmful than Next since it is mitigated because the distance between the source and the noise receiver. Fig. 2 is an example of Fext.

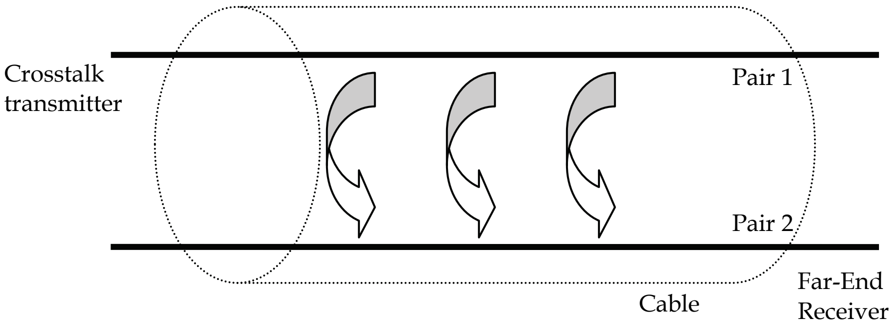


Fig. 2. Illustration of Fext

Techniques such as DSM (dynamic spectrum management) and MIMO (multiple-input multiple-output) schemes try to find a controlled injection of spectrum in DSL systems so that the resulting crosstalk can assume acceptable performance values (Starr et al., 2003), (Ödling et al., 2009).

2.2 Wireless Broadband Networks (WBN)

A large number of wireless technologies exist and other systems still being under design. These technologies can be distributed over different network families, based on a system scale (Nuaymi, 2007):

- A wireless personal area network (WPAN) is a data network used for communication among data devices close to one person;
- A wireless local area network (WLAN) is a data network used for communication among data devices: computer, telephones, printer and personal digital assistants (PDAs). This network covers a relatively small area, like a home, an office or a small campus (or part of a campus);

- A wireless metropolitan area network (WMAN) is a data network that may cover up to several kilometres, typically a large campus or a city;
- A wireless wide area network (WWAN) is a data network covering a wide geographical area, as big as the Planet. WWANs are based on the connection of WLANs, allowing users in one location to communicate with users in other locations.

There are many applications for wireless networks. One of the first uses for wireless technology was used as an alternative for traditional wired voice telephony, the narrowband wireless local-loop systems (Andrews et al., 2007). These systems, called wireless local-loop (WLL), were quite successful in developing countries whose high demand for basic telephone services could not be attended using the existing infrastructure.
However, as conventional wired technologies such as DSL and cable modems began to be deployed, wireless systems had to evolve to support much higher speeds so that they could become competitive. A specific very high speed system called local multipoint distribution system (LMDS) was developed, capable of supporting several hundreds megabits per second in millimeter wave frequency bands, such as the 24 GHz and 39 GHz bands.
A WBN is a high data rate (of the order of Mbps) WMAN or WWAN. A WBN system can be seen as an evolution of WLL systems, mainly featuring significantly higher data rates. While WLL systems are mainly destined for voice communications and low data rate (i.e. smaller than 50 kbps), WBN systems are intended to deliver data flows in Mbps (Nuaymi, 2007).
There are a significant number of WBN systems with different and specific characteristics. Table 2 presents a comparison between the main WBN technologies (Andrews et al., 2007):

Parameter	**Fixed WIMAX**	**Mobile WIMAX**	**HSPA**	**Wi-Fi**
Meaning	Worldwide Interoperability for Microwave Access		High-Speed Packet Access	Wireless Fidelity
Standards	IEEE 802.16 - 2004	IEEE 802.16e - 2005	3GPP* release 6	IEEE 802.11 a/g/n
Frequency band	3.5 GHz and 5.8 GHz	2.3 GHz, 2.5 GHz, and 3.5 GHz	800/900/1,800/1,900/ 2,100 MHz	2.4 GHz and 5 GHz
Typical coverage	3–5 miles	< 2 miles	1–3 miles	< 100 ft indoors; < 1000 ft outdoors
Mobility	Not applicable	Mid	High	Low
Peak downlink (DL) data rate	9.4 Mbps in 3.5 MHz with 3:1 DL-to-UL ratio; 6.1 Mbps with 1:1	46 Mbps with 3:1 DL-to-UL ratio; 32 Mbps with 1:1	14.4 Mbps using all 15 codes; 7.2 Mbps with 10 codes	54 Mbps shared using 802.11 a/g; more than 100 Mbps peak layer 2 throughput using 802.11 n
Peak uplink (UL) data rate	3.3 Mbps in 3.5 MHz using 3:1 DL-to-UL ratio; 6.5 Mbps with 1:1	7 Mbps in 10 MHz using 3:1 DL-to-UL ratio; 4 Mbps using 1:1	1.4 Mbps initially; 5.8 Mbps later	

* Third-generation Partnership Project

Table 2. Comparison between main WBN technologies

Our focus in this section is to analyze WBN systems called pre-WIMAX systems. These systems use products which are claimed to be based on the IEEE 802.16 standard. They can deliver data flows up to 30 Mbps and their performance levels are close to the ones expected of WIMAX. Fig. 3 is a classical example of a pre-WIMAX system.

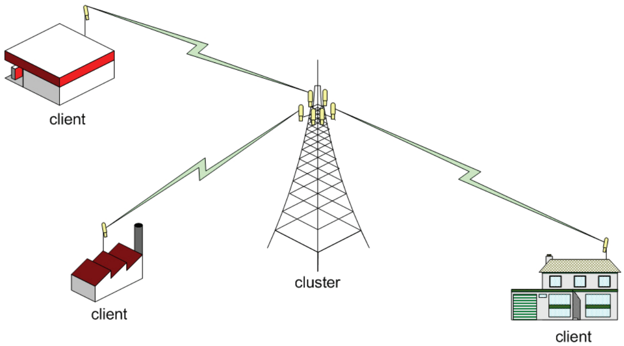


Fig. 3. Example of pre-WIMAX system

In this system we have a station server (or cluster) using six directional antennas (60° aperture) for an omni coverage. However, systems using 360°, 180°, 120° or 90° antenna apertures are also possible.

Pre-WIMAX systems can operate in the 2.4 GHz, 3.5 GHz, 4.9 GHz, 5.2 GHz and 5.8 GHz frequency bands. Depending on national regulation laws, pre-WIMAX systems can work in both licensed and license-exempt frequencies.

The main problem in pre-WIMAX systems is interference. Interference is an unwanted disturbance that can affect the overall system performance. Such disturbance is due to electromagnetic radiation emitted from diverse sources. It can appear in a different number of forms:

- Intra-system (within its own network, i.e., equipments working on the same frequency);
- Inter-system (external to its network, i.e., others systems working on the same frequency);
- External (other sources, not network but RF equipment, such as machinery and generators).

Traditional approaches to interference reduction include the use of power control, opportunistic spectrum access, intra and inter-base station interference cancellation, adaptive fractional frequency reuse, spatial antenna techniques such as MIMO and SDMA (space division multiple access), and adaptive beamforming, as well as recent innovations in decoding algorithms (Boudreau et al., 2009).

3. PLC applications across access networks

3.1 Using PLC on DSL systems

Consider the scenario of small or medium-size enterprise using a VDSL system (VDSL1 or VDSL2) as broadband access. In this system, the demand for higher data rates is increasing, especially when it uses services that require high bandwidth such as video conferencing and internet protocol television (IPTV). Thus, the proper control of crosstalk becomes a keystone in the operation of such systems.

Fig. 4 is a typical example of access network topology using VDSL systems on a fiber-to-the-curb (FTTC) scenario. A primary optical fiber cable connects the central office (CO) to a street cabinet, and from there, a cooper pair is used to reach the customer premises equipment (CPE), i.e., the VDSL modem.

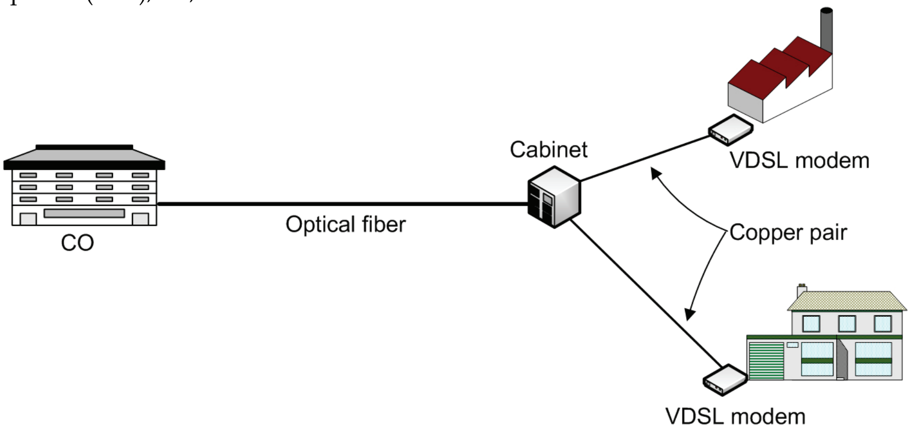


Fig. 4. Access network topology using DSL system on a FTTC scenario

VDSL is designed to operate over shorter loops. Consequently, VDSL equipment is positioned in cabinets, with the typical loop length being below one kilometer (Ödling et al., 2009).
A proposed use of the PLC is in the loop between the cabinet and VDSL modem. In this case, the PLC is used as a remote trigger for a system that changes the wires configuration on a telephone cable. The system shown in the Fig. 5 illustrates this use.

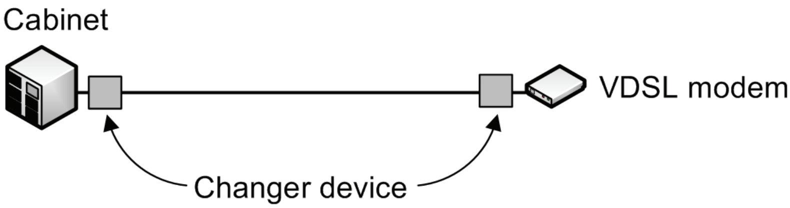


Fig. 5. Changer device using a PLC and a stepper motor

The changer device is comprised of a PLC and a stepper motor (an electromechanical system which converts electrical pulses into discrete mechanical movements). The main objective of this device is to modify the wire arrangement so that the resulting crosstalk has its values changed. It is obtained by changing the metal contacts located at the both extremities of the cable at the same time. This is the reason for it to be necessary to have two changer devices in the proposed configuration.
Obviously, this solution is a first approach method for reducing crosstalk impact, having a very specific application which is focused on heavy users who need a high quality transmission system with reasonable costs. A basic limitation of this proposed scenario is that it has no real use in a VDSL system using a single wire pair.
This scenario can be adapted to other DSL technologies. Fig. 6 shows an access network example for ADSL2+ technology.

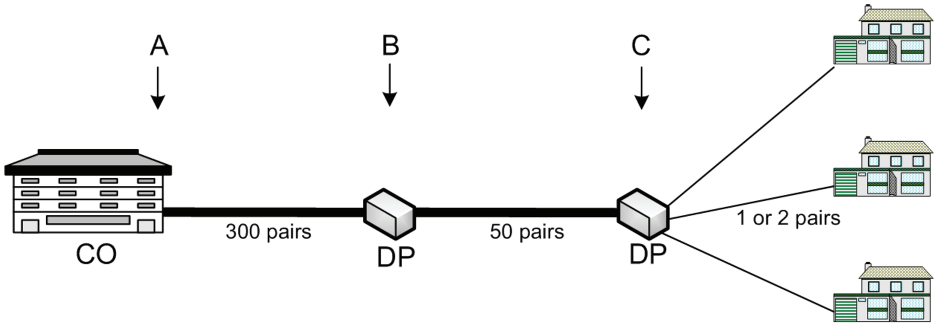


Fig. 6. Access network for ADSL2+ system

The copper plant is a star network which has fewer lines running together, until individual wire pairs finally reach their respective CPE (some configurations can use two wire pairs). Distribution points (DP) are the connection between cables of different gauges and wire numbers.

The changer device can be used between points A and B or between points B and C. The idea is the same as shown in Fig. 5, i.e., using the changer device to rearrange the layout of the metal contacts.

3.2 Using PLC on Wireless Broadband Networks (WBN)

The basic idea using PLC for interference reduction on WBN is to use it as an antenna azimuth automatic controller (AAAC).

Azimuth is the horizontal angular distance from the northern point of the horizon to a given referent direction. By changing the antenna's azimuth, the radiated power in a given direction is altered. As a result, it is possible to reduce the interference caused by frequency reuse within the same area of wireless coverage. In this utilization, the PLC is again used in conjunction with a stepper motor to perform the azimuth change.

The initial premise of this solution is to identify that interference is happening across the system. This can be done using some form of performance analysis system (depending on the equipment used, this could be a type of software for analyzing network performance) or collecting performance metrics from MIB (management information base) files, for instance.

Once the occurrence of interference is identified, using the system described in Fig. 7, it is possible perform a rapid and effective intervention on the system, thus reducing the interference effects.

Fig. 7 is an example of this proposed configuration. The PLC is connected to the stepper motor, which is responsible for the movement of set of APs (access points). AP represents the antenna of a radio transmission system. The number of APs will depend on the configuration of each system. The system shown in Fig. 7 uses six APs, where each antenna has a horizontal aperture of 60˚. Others configurations, using horizontal apertures of 90˚, 120˚ or other values are also possible.

The PLC control system consists of a computer (not shown in Fig. 7), which is responsible for sending commands to the PLC, thereby controlling the movements of the stepper motor.

A basic ladder logic program for stepper motor control is shown in Fig. 8. In this case, i-TRiLOGI software (i-TRiLOGI, 2009) was used to perform an off-line simulation of the PLC's program on a personal computer.

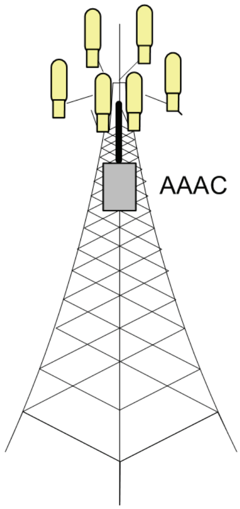
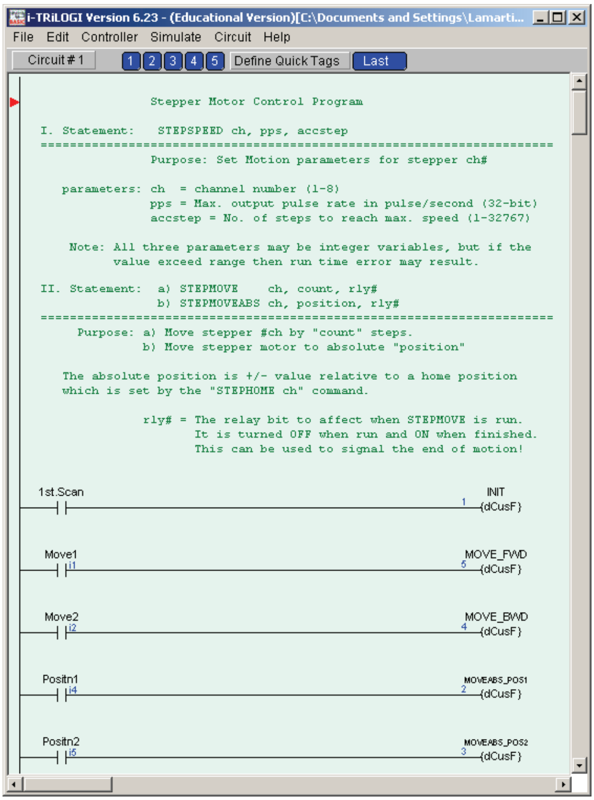
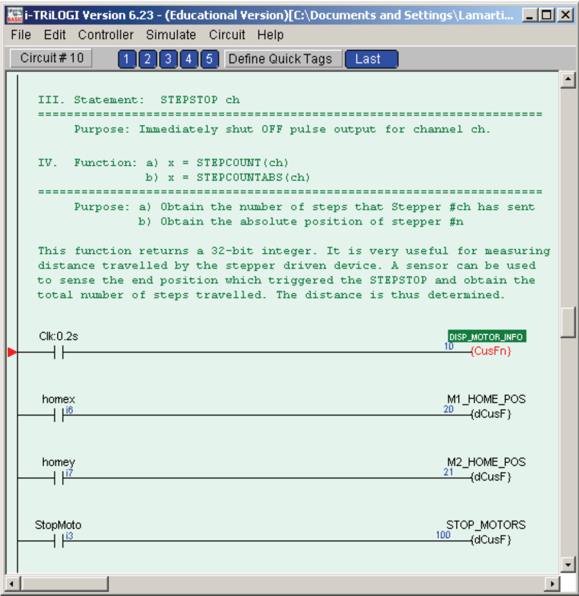


Fig. 7. Example of PLC application on WBN



(a)



(b)

Fig. 8. Ladder logic program for stepper motor control: a) Code to control speed and movement, b) Code to control stop

4. Conclusion

We have presented alternative PLC applications on access networks, particularly in DSL systems and wireless broadband networks. Details about technical implementation possibilities are beyond the scope of this chapter; however the proposed applications use well known and easily accessible equipments and devices.

Since the PLC has relatively low cost, high operational speeds and multiple usage characteristics, its utilization across access networks provide a low-priced and practical method for mitigating problems related to the network performance.

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