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Wireless-Broadband over Power Lines Networks: A Promising Broadband Solution in Rural Areas

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Abstract—In rural areas and remote areas the expenditure for new projects related to broadband communications is deterred. In this paper hybrid Wireless-Broadband over Power Lines (W-BPL) technology, suitable for rural and remote areas is presented. This hybrid approach employs BPL technology for the transmission of communication signals via the medium voltage (MV) grid and wireless technology for providing broadband access to end users. The advantages and opportunities of this hybrid solution are presented through the deployment of a trial hybrid W-BPL network in Larissa, a rural area in central Greece. This network offers broadband access and smart grid applications along a 70 km MV power grid. The supported services along with network performance issues are discussed.

Index Terms—Broadband over Power Lines (BPL), Quality of Service (QoS), power supply grid

I. Introduction

Though the widespread the widespread availability of information communication technologies (ICT) and the relevant opportunities have been already achieved in densely populated areas and developed regions, there are still vast geographic regions where the diffusion of such technologies is still an open issue [1]. This gives rise to a new form of social exclusion known as the digital divide, as ICT may improve educational services, accelerate the economic development and provide higher living standards. The deployment of ICT systems in rural and remote areas - characterized by low population density and long transmission distances - has to overcome several obstacles.

The main problem in providing ICT to rural and distant areas is the increased cost which depends on the special characteristics of each area and the communication system used. The low income per capita and the small number of potential users prevent the development of broadband technology platforms in such areas.

Apart from cost another adverse characteristic is the long distances of remote users along with the adverse geographic and climatic conditions. Furthermore, apart from the last mile network, the provision of broadband services to rural areas requires appropriate middle mile network for the interconnection of the access network to the high-capacity backbone network. The distance of remote communities from the backbone network increases significantly the end user cost constituting another important factor contributing to the digital divide.

As the potential deployment and use of wired systems is excluded due to the extremely high installation cost, it is clear that the last mile network must be wireless [2], [3]. The 802.11 standards offer new possibilities not only for broadband wireless access but, also, as a form of wireless connection to the distribution network [4]. Apart from WiFi technology, other solutions based on 802.16 standards, local multipoint distribution systems (LMDS), satellite communications or hybrid networks have been proposed.

Another promising solution seems to be the hybrid wireless-broadband over power lines (W-BPL) communications technology. Hybrid W-BPL networks combine the ubiquitous power distribution grid with WiFi technology to create a reliable, high-capacity and cost effective broadband access network [5]. The way W-BPL end users receive data is similar to the traditional wireless one, except that last mile access is accomplished through the MV power lines. This constitutes the main advantage of W-BPL technology as there is no need to install new communications cables [6]. In such networks signals propagate along the MV power lines in the frequency range 1-34MHz together with electric power at 50 or 60 Hz. Users may be connected to BPL networks either through WiFi hot spots embedded into the BPL units or through the low voltage (LV) lines using appropriate BPL modems.

In addition to broadband services to end users, W-BPL networks offer a great variety of potential applications such as home automation, public safety communications and, most of all, management of the power network including smart grid applications, network monitoring, electronic meter reading, negawatt applications [7].

The low installation cost and the variety of potential applications offered by the ubiquitous power distribution grid constitute the main advantages of hybrid W-BPL technology

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for providing broadband services in rural and remote areas. Hybrid W-BPL technology and its advantages have been tested and evaluated in a trial network recently installed in the area of Larissa, a rural area in Greece.

The rest of the article is organized as follows. In Section II an overview of W-BPL technology is given. The main motivation for choosing the region of Larissa for the trial deployment is highlighted in Section III, whereas in Section IV the system parameters and architecture are presented. In Section V the services provided and the respective quality of service (QoS) techniques used are presented. Some indicative measurements are given in Section VI. Section VII states concluding remarks.

II. Overview of BPL Technology and Hybrid W-BPL Access

BPL technology exploits the electrical power supply grid to transmit communication signals. BPL networks are installed onto the ubiquitous MV power grid to deliver broadband services. As the measurements from the trial network presented in Sec.6 show, BPL technology may be considered as an alternative broadband access solution with comparable quality compared to standard solutions such as DSL. Hence, in areas where, due to increased cost or to technical reasons, standard solutions are not available, BPL technology provides an alternative cost effective solution.

The key idea behind BPL systems is the transmission of communication signals via the MV power lines together with the electric current (see Fig.1). Since the power grid is designed for the transmission of electric power and not for communications, the BPL transmission via the overhead MV grid differs significantly from typical wired signal transmission [8]. Thus, the available bandwidth per power line is limited. The maximum number of users depends on the topology and the physical properties of the cable, on EMI constraints [9] and on the individual QoS demands of various users [10].

BPL systems are usually installed onto the MV grid as shown in Fig. 2. Information is injected into the MV lines employing couplers installed at appropriate positions, usually at HV to MV substations. These couplers are responsible for traffic aggregation and for the connection to the backhaul which may be realized either with a point-to-point wireless link, a fiber optic or a cable network. In rural areas where none of these possibilities exists, a satellite link may be used.

From a HV to MV substation many MV lines start, each one connected to the aggregation point via its own BPL unit. BPL units may support several operations; they inject signals into the MV lines, regenerate and amplify signals already propagating via the MV lines, and extract signals offering wireless access. When remote users must be served, repeaters are necessary to mitigate the adverse propagation characteristics of the MV lines [11]. The critical factors affecting signal propagation are cable attenuation, reflections at the branching points and at the mismatched terminations of the MV lines causing frequency selective fading, and the high noise environment. To minimize cost and complexity, current BPL systems incorporate all operations into a single unit (BPL-GEN2) [12].

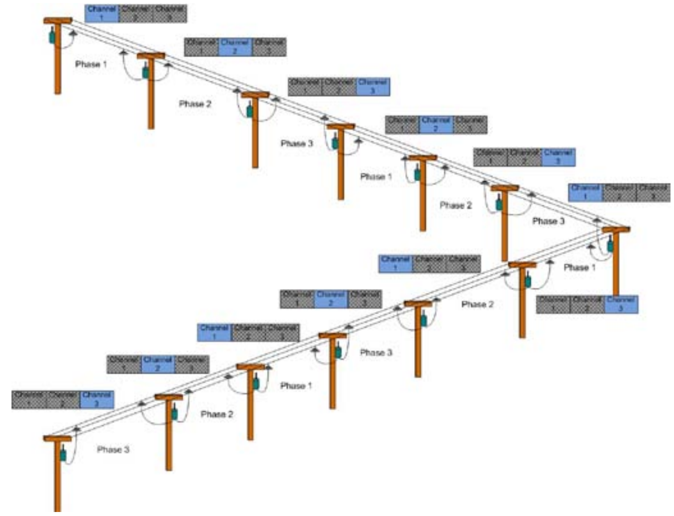

Fig. 1. BPL phase and channel assignment and channel allocation along the MV line.

In general, a subscriber may be connected to the MV/BPL network in two ways. With regard to the wired way, users are connected through the LV lines [13] using appropriate BPL modems usually installed indoor at their meter unit. For various reasons LV lines are not used for last mile access. With regard to the wireless way, BPL units extract the signal from the MV power lines and convert it into totally compatible IEEE 802.11a/b/g signals. Thus, the BPL units may also serve as a wireless interface transforming the BPL network into a hybrid W-BPL network.

BPL transmission usually employs the 1-34 MHz frequency range. This range can be extended up to 100 MHz but it is subjected to regulations issues. Better spectrum utilization is achieved through the use of orthogonal frequency division multiplexing (OFDM). OFDM provides an increased resistance to signal distortion, higher bit rates and frequency selective capabilities suppressing certain frequencies, because they are either strongly disturbed or allocated to other services.

III. Motivation for the Trial W-BPL Network

The trial network to be presented has been installed in Larissa, a rural area in central Greece. The city of Larissa is a commercial and industrial centre and is surrounded by a vast plain. Although the population of the greater area is around 250,000, the area considered is densely populated in the city, whereas it is covered by small villages and agricultural fields in the rest. Since the hybrid W-BPL network was installed outside the city, the inhabitants around the network deployment are approximately 7000.

The hybrid W-BPL network was deployed in Larissa for two reasons. The first was the need to remotely monitor and control a high number of irrigating pumps installed in the

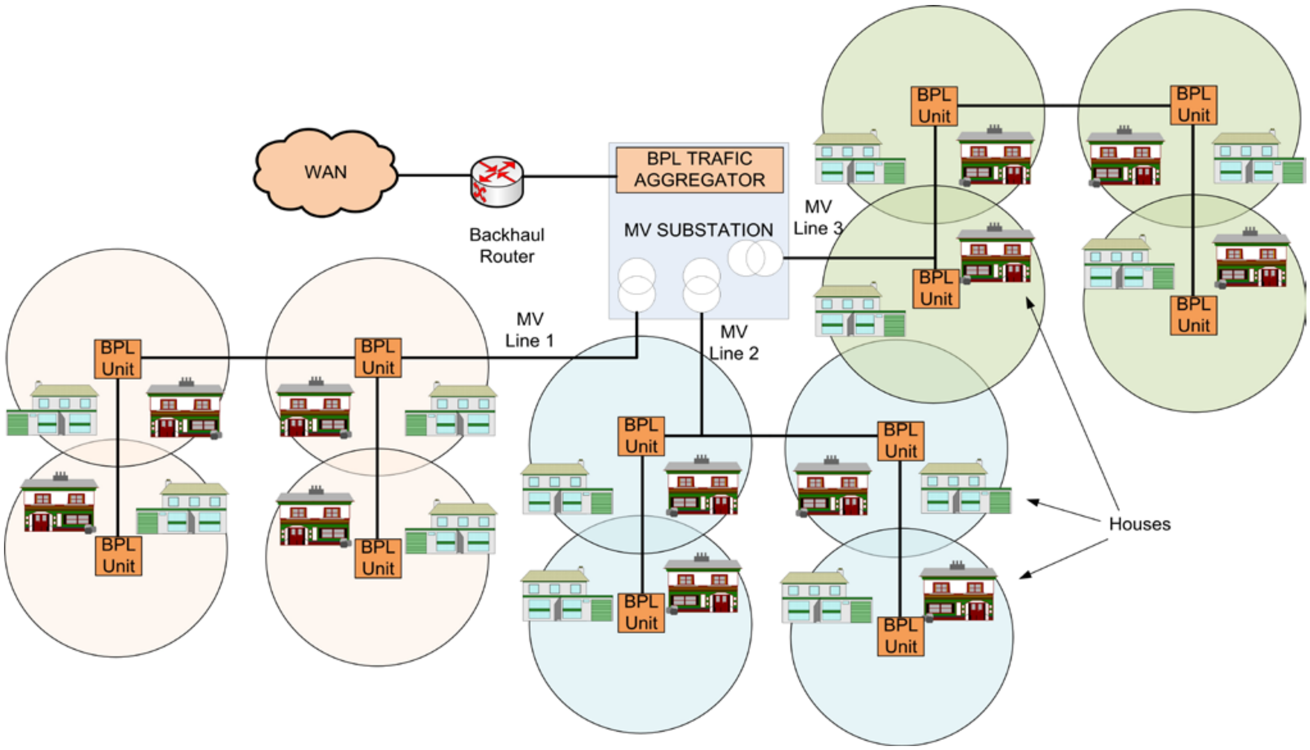

Fig. 2. Power grid incorporating hybrid W-BPL technology.

region aiming at reducing their power consumption during the peak demand summer period. Through this smart energy function, the Greek utility company wishes to reduce the probability of a potential black out. The second motivation related to the installation of a hybrid W-BPL network in this region was to provide broadband access to local population. The available DSL connections do not cover the vast rural area around the city of Larissa, necessitating the deployment of alternative technologies.

IV. System Specifications and Network Topology

The MV power supply grid in Greece is a 20kV, overhead and underground 3-phase 4-wire network following a tree architecture. The LV distribution network stemming from MV to LV transformers, provides 220V electric power to end users. Both the MV and LV power grid may be used for BPL transmission, but for the purposes of the trial project only the overhead MV network was utilized. In particular, two overhead MV lines of 70km total length have been used. Though the poles are spaced by approximately 50m, BPL units were placed at distances ranging approximately from 500m to 800m.

The network deployed consists of 110 BPL units installed on equal in number MV poles at appropriate locations. Each BPL unit is equipped with one transceiver employing BPL technology and two wireless interfaces. The BPL transceiver is responsible for signal transmission via the MV lines. The first wireless interface is used as a WiFi hot spot providing access to end users. The second one operates as backup being activated when the BPL transceiver recognizes that the connection to the neighboring BPL unit is lost. Both wireless interfaces support the IEEE 802.11 b/g protocols as users equipment is compatible with this technology.

The BPL transceivers used in the trial project consist of three basic modules. The first one is the coupling unit employed either to extract from or to inject the BPL signal into the MV line. The second unit is the bandpass filter used to isolate three 10 MHz channels as the available frequency range (1-34 MHz) is separated into different channels occupied for each transmission between successive BPL units on a round robin basis. This separation into three frequency channels is used to suppress interference -as different frequency bands are occupied between successive units eliminating the interference- and to achieve maximum utilization of the available bandwidth. To further reduce interference, the three phases are alternatively used, as shown in Fig. 1, resulting in a more sophisticated utilization scheme. The third unit is the BPL modem which is responsible for controlling the entire protocol stack and the operation functions. Also, one of the BPL modem basic functions is BPL signal regeneration; thus each BPL unit acts as a repeater.

Both MV lines employed in the trial network stem from an HV to MV substation where the initial injection of BPL signals into the MV wires is done (see Fig.3). Also, the network operating center (NOC) was installed at this substation. The NOC acts as aggregator of the total traffic produced in the two lines of the hybrid W-BPL network as well as the control center controling the operations over the network. It also incorporates the network management software for monitoring and remote controlling the power network and the application servers related to broadband access (e.g. VoIP, Network Management). To connect the hybrid W-BPL network with the wide area network (WAN),

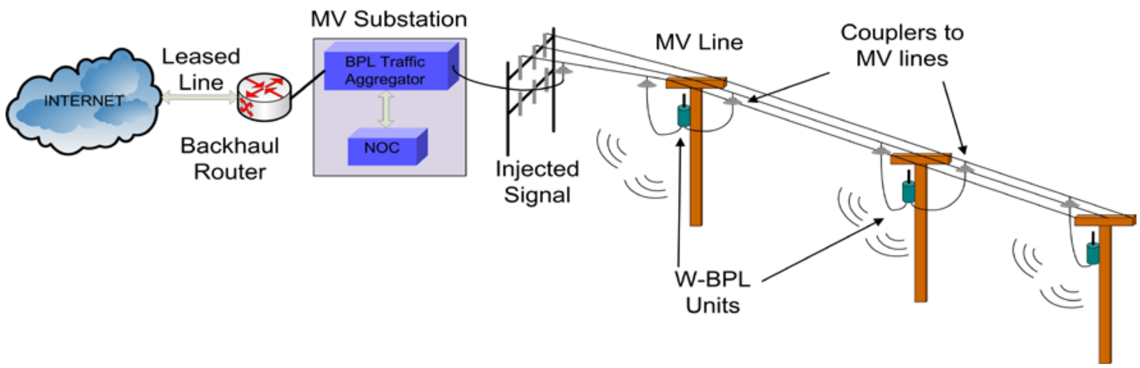

Fig. 3: The structure of power network connection to backhaul employing BPL technology.

the first BPL unit of each MV line is connected to the NOC which, in turn, is connected through the backhaul router via a 2Mbps ADSL line to the Internet.

V. Assuring QoS

Assuring QoS for the services offered by the W-BPL network was a key issue for the Larissa trial project. Each service supports different QoS requirements as depicted in Table 1 [14]. The services and applications appearing in Table 1 are smart grid applications and broadband applications. Since the main motivation for the W-BPL network deployment was the monitoring and control of the power grid, smart grid applications were assigned higher priority over broadband applications.

The first service offered by the W-BPL network was the remote monitoring and management of users equipment -in the specific deployment, of the irrigating pumps installed along the two MV lines-. This service was of highest priority for the specific project. As a service class, it has similar characteristics with multimedia messaging, since it is a low-bandwidth application with strict-delay constraints. The packets generated from this activity were assigned the highest priority.

The surveillance of the power grid was a smart grid application also implemented in the Larissa project. It required the installation of IP cameras at critical locations of the network. This application has similar characteristics with high quality video streaming, it is bandwidth demanding, delay tolerant and jitter intolerant.

Another smart grid service supported by the trial network was the collection of data generated from LV meters and from temperature and humidity sensors installed at appropriate network locations. The difference of this service class, from the manage and monitor applications (see Table 1), is that it involves one way communication between the end-devices and the NOC. It is considered as a low-bandwidth, delay-aware application having the characteristics of simple messaging service class.

Another critical application provided by the Larissa W-BPL trial network was VoIP. It was essential for the project since it would enable communications of the utility crew performing the maintenance of the MV power grid. VoIP is a low-bandwidth demanding application with low-delay

Table 1: Service Class QoS Characteristics

Applications & Services	Description	Priority	Data rate in kbps	Delay in msec
Manage & Monitor	Multimedia messaging	1	8	100
Surveillance	High quality video streaming	2	2000	100
Data recordings	Simple messaging	3	1000	200
VoIP	Data and media telephony	4	64	100
Broadband Access	Lightweight browsing	5	64	200

constraints. It was accomplished by installing a VoIP server at the NOC. Packets destined for the VoIP server were assigned a low priority (See Table 1).

Finally, broadband access has also been supported offering lightweight browsing to subscribers located within the coverage of the W-BPL network. This service has low bandwidth demand and is tolerant to delay, thus being a best effort service assigned the lowest priority.

VI. Performance Measurements

To assess the quality of the IP services provided by the hybrid W-BPL network deployed in Larissa, Greece, and to study the proposed network architecture with regard to offering smart grid services and broadband applications to rural and remote areas, measurements concerning the network delay and network throughput were performed

Fig. 5 depicts the minimum, average and maximum delay of signal transmissison between certain BPL units and the NOC. The units wherefrom measurements were taken were chosen based on their average distance from the NOC. It can be observed that the delay increases for those units being at a distance from the NOC ranging from 2.5km to 3.5km. As distance exceeds 3.5km the delay becomes lower. The reason explaining this behavior is that longer distances lead to longer

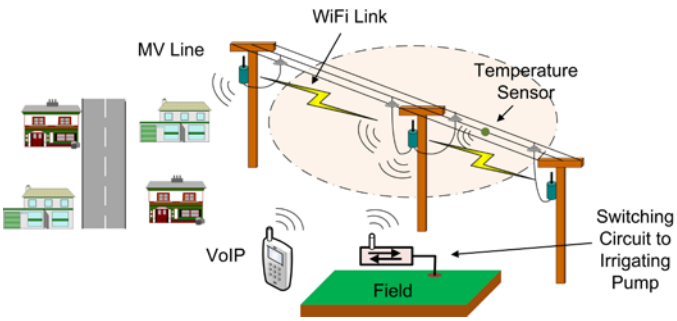

Fig. 4. Schematic diagram of the hybrid W-BPL network deployed offering last mile access and smart grid applications.

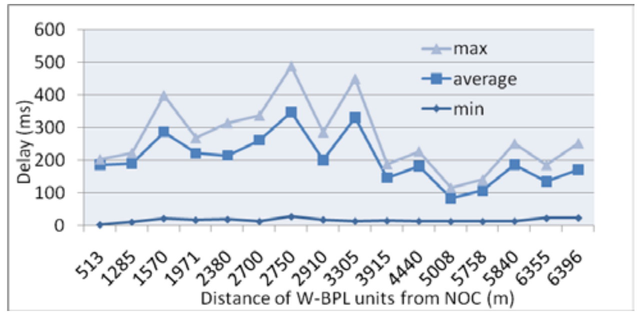

Fig 5. Maximum, average and minimum transmission delay concerning the connection of certain BPL units and the NOC.

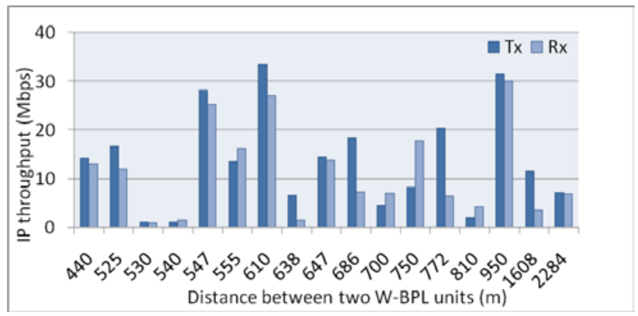

Fig. 6. Transmitting and receiving rates of BPL links.

BPL segments. Through the tastings performed upon installation, it was observed that a sequence of BPL units that exceeds six in number –corresponding to a distance of approximately 3km- may lead to signal distortion due to multipath propagation. This was also observed in the Larissa network and dealt with by activating some of the wireless connections when the signal distortion was found high. So, longer distances necessitated the activation of a wireless connection, bypassing the respective wired BPL connections. This architecture results in bandwidth reduction caused by the activation of wireless connections. On the other hand, interference caused by neighboring transmitting BPL units is avoided, thus providing an important signal quality advantage. This constitutes an important advantage of the hybrid network architecture over the single one. An average delay of 200ms measured shows that the respective QoS requirements of different applications are met throughout the pilot network most of the time.

In Fig. 6 the transmitting and receiving rate of the W-BPL units are plotted with respect to distance. BPL units have the multipoint characteristic enabled. This means that each BPL transmitter can establish BPL links between multiple BPL receivers, not necessarily neighboring ones. The distance on the horizontal axis is the distance of a point to point link between two BPL units. From the measurements it is deduced that the channel conditions vary with the topology of the grid, the type of the cables, the number of intermediate BPL units transmitting along the same link – on a different phase or channel-. Also, signal reflections caused by other devices which may be installed on the poles such as insulators, transformers and MV circuit breakers may impair the transmission conditions. The above, together with the low level of the injected Power Spectral Density (PSD) imposed by the operation of the nearby military airport, were the main reasons for the data rates observed, varying around an average value of 14Mbps. This throughput is per BPL link and per MV branch offering a total aggregate throughput close to 80Mbps (IP level) supported by the technology used [12]. Further increase in PSD [15] would lead to multiple aggregate data rates as observed in [9], but in the Larissa project PSD increase was prohibited.

The measurements presented above indicate that W-BPL offers the broadband communications platform for smart grid applications and a good alternative solution for broadband communication in rural areas. It is verified that W-BPL deployment and performance depends drastically on the site conditions and the quality and topology of the power grid. The use of the OFDM technique [9] and the standardization of this technology will enhance network performance and scalability.

VII. Conclusion

From the experimental results based on the Hybrid BPL network deployed in Larissa, it derives that the integrated W–BPL solution constitutes a viable solution for providing smart grid services to power supply power grid. The main advantage of this hybrid technology are the low realization cost and the high quality smart grid services offered, which have been achieved despite the limitations concerning the frequency spectrum used. In particular, only the frequencies between 1-30MHz were used due to the restrictions of a nearby military airport. Applying the new regulations related to the frequency spectrum used, which are imposed by international standardization organizations, frequencies above 30MHz can be used. Thus, the QoS level offered by the hybrid network will be improved, while at the same time possibilities for new services will arise. At the time, W-BPL networks and smart grid capabilities offer great opportunities to farmers and the electrical utility, introducing a new era in the energy field.

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IX. BIOGRAPHIES

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