HomePlug AV for Digital Out-of-Home (DOOH) Advertisement applications: results and experiences from a real-world deployment

Pere Tuset, Roberto Romero, Pere Barberán, Léonard Janer, Marc Llenas, Jorge Luna

Abstract — **One of the main challenges of DOOH (Digital Out-of-Home) Advertisement is to distribute multimedia contents to a network of digital displays located at a shopping mall, as wired and wireless technologies are not well suited for the task due to technical restrictions (limited propagation, crowded spectrum, etc.) and economic constraints (overall cost of the deployment). In this sense, this paper presents the results and experiences from deploying a PowerLine Communication (PLC) system based on the HomePlug AV standard in a shopping mall to distribute real-time multimedia contents. Both the results and experiences show that HomePlug AV is an enabling technology for such scenarios as it provides enough bandwidth at a reduced cost.**

Keywords — **Digital Out-of-Home Advertisement, HomePlug AV, PowerLine Communications.**

I. Introduction

THE integration of computing technologies, including embedded computers and flat-screen displays, as well as the ubiquitous availability of broadband Internet access has enabled the (r)evolution of traditional out-out-home advertisement, e.g. in shopping malls, to a digital format. This new advertisement paradigm is usually known as Digital Out-of-Home (DOOH) Advertisement and has many advantages to both the advertiser and the manager of the advertising network. But compared to traditional means of advertisement, e.g. paper, there are different challenges that DOOH networks need to address in order to provide an adequate level of service to the advertiser.

One of the most prominent challenges of DOOH is related to telecommunications, as the Internet is used to distribute the multimedia contents to on-site advertising screens. The distribution of such multimedia content is divided into two well-differentiated parts; Internet access and local distribution. On the one hand, Internet access can be solved by using any broadband technology, either wired or wireless. Typical solutions to provide Internet access to DOOH networks are based on xDSL (Digital Subscriber Line) or HFC (Hybrid Fiber-Coaxial) networks, and 3G mobile technologies (including UMTS/HSPA) are used as backup lines or wherever no wired access networks are available. On the other hand, local distribution of multimedia contents at the shopping mall can also be solved by using either wired or wireless technologies. Typical wired solutions to provide local distribution of multimedia contents are based on Ethernet (IEEE 802.3), whereas wireless solutions are usually based on Wi-Fi (802.11) [1, 2, 3].

Nevertheless, neither Ethernet nor Wi-Fi is well-suited for DOOH environments for both technic and economic reasons. On the one hand most shopping malls impose restrictions to the deployment of new communications infrastructure based on Ethernet because the installation causes discomfort to visitors and stores. Additionally, the cost of deploying such new communications infrastructure is typically unaffordable to network operators taking into account the size of shopping malls and that advertising nodes are sparsely located. On the other hand, Wi-Fi has poor signal propagation characteristics considering its operating frequency and the deployment context (different floors, concrete walls, metallic doors, people moving, etc.). Furthermore, the 2.4 GHz ISM (Industrial, Scientific and Medical) band is crowded with other Wi-Fi networks and other wireless technologies (i.e. Bluetooth) that act as an interference, thus degrading the quality of the signal.

Taking all this into account, the article presents the results and experiences from a pilot deployment using HomePlug AV technology to distribute multimedia contents within a shopping mall. To author's knowledge, this is the first real-world deployment of the HomePlug AV technology in such environments and, thus, the results and experiences obtained from the deployment can be of interest to other researchers, engineers and technicians working in the field of PowerLine Communications.

The rest of the article is organized as follows. Section 2 presents an overview of the HomePlug AV technology that enables broadband data communications over the power line. Section 3 describes the evaluation context and the performance parameters that have been studied in the project. Next, Section 4 states the results obtained from the measurements that have been conducted in the

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Pere Tuset, Roberto Romero, Pere Barberán and Léonard Janer are with Netlab, Secció de Projectes de Transferència de Tecnologia i Coneixment, Fundació TecnoCampus Mataró-Maresme. Av. Ernest Lluch 32, E08301 – Mataró, Spain. (Telephone: +34.93.169.65.00, E-Mail: netlab@tecnocampus.cat).

Marc Llenas and Jorge Luna are with Lunar New Media S.L. (ALOOHA™). Av. Ernest Lluch 32 - Planta 2, Oficina 13. E08301 – Mataró, Spain. (Telephone: +34.93.702.44.42, E-Mail: info@alooha.es).

shopping mall. Finally, Section 5 summarizes the results obtained and presents the conclusions obtained from the work carried out within the project.

II. An overview of HomePlug AV

HomePlug AV [4, 5, 6, 7] is a *de facto* standard promoted by the HomePlug Powerline Alliance that enables to interconnect network devices using the power line. The HomePlug AV standard was launched in year 2007 and allows an access bandwidth of up to 200 Mbps at the physical layer. Furthermore, HomePlug AV can coexist and is interoperable with HomePlug 1.0, the former version of the standard, that was launched in year 2001 and allows an access bandwidth of up to 14 Mbps (and up to 85 Mbps using the proprietary extensions introduced by Intellon—Atheros) at the physical layer.

Technically speaking, the HomePlug AV standard defines both the physical (PHY) and link (MAC) layers to enable the transmission of digital data through the power line. At the physical layer HomePlug AV uses an overall bandwidth of 28 MHz, from 1.8 to 30 MHz, with an OFDM (Orthogonal Frequency Division Multiplexing) scheme. The OFDM scheme was selected because it enables to adapt to the challenging and changing characteristics of the power line environment; for instance, it is robust against the frequency selective channel response and the impulsive and broadband noise present in the power line. The OFDM scheme has an overall of 1155 carriers, with a frequency separation of 24.414 kHz, but only 917 of those carriers are used to transmit useful information, the rest are used for other tasks such as channel estimation. Each OFDM symbol has length of 40.96 µs and the guard interval between symbols can be configured to be of 5.56, 7.56 or 47.12 µs. Depending on the SNR (Signal to Noise Ratio) at the receiver each carrier is independently modulated using a coherent digital modulation technique such as BPSK (Binary Phase Shift Keying), QPSK (Quadrature Phase Shift Keying) or {8, 16, 64, 256, 1024}-QAM (Quadrature Amplitude Modulation). Additionally, the physical layer also includes a FEC (Forward Error Correction) mechanism implemented using a convolutional turbo code that uses 1/2 or 16/21 rates depending on the channel conditions.

The HomePlug AV link layer defines two access mechanisms, with and without contention, depending on the QoS (Quality of Service) required by each traffic flow. On the one hand, the contentionless access mode is based on a TDMA (Time Division Multiple Access) technique that allows to make bandwidth reservations, as well as to limit delay, jitter and packet loss. To manage the network resources a CCo (Central Coordinator) takes the responsibility of attending resource reservations from the STA (Stations) and assigning time slots in which the stations can transmit information. On the other hand, the contention mode is based on a CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance) and offers four priority levels to which stations can map their traffic according to its QoS (Quality of Service) requirements.

Finally, because the power line is a shared transmission medium, the HomePlug AV standard includes security mechanisms that ensure the confidentiality of the data transmitted over the wires. Specifically, HomePlug AV uses private key cryptography scheme with a 128-bit AES (Advanced Encryption Standard) key. Also, the standard includes an automatic key management protocol that is responsible of automatically setting up the security mechanisms in a way that is transparent to the end user.

III. Evaluation Context and performance parameters

The measurements presented in this paper have been carried out at "*Centre de la Vila*", a mid-sized shopping mall located in the Olympic Port of Barcelona. The shopping mall is divided into two floors and occupies an overall of twenty-two thousand square meters and has an approximate number of five million visitors each year.

Currently there are twelve dPoP® (Lunar New Media's digital Point of Presentation advertising support devices) deployed within the shopping mall, four in the first floor and six in the second floor as displayed in Figures 1 and 2. There are two types of dPoPs, single-sided and double-sided, depending on their location.

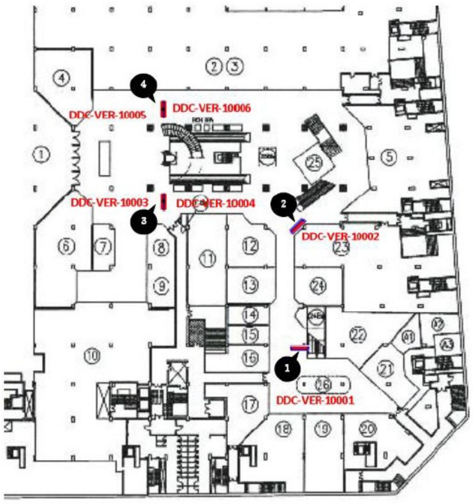

Fig. 1. First floor of the shopping mall, with two single-sided dPoPs and two double-sided dPoPs.

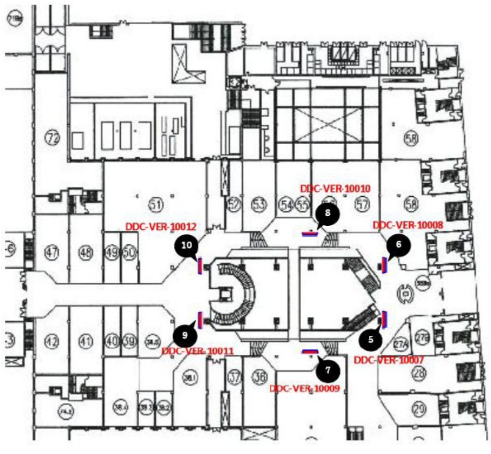

Fig. 2. Second floor of the shopping mall, with an

overall of six single-sided dPoPs.

The network topology used to distribute the real-time multimedia contents to the different dPoPs of the shopping mall is depicted in Figure 3. As it is possible to see, all the dPoPs in the first floor have been connected directly through the power line to the header modem, which is located together with the xDSL router in a separated service room. On their behalf, all the dPoPs in the ground floor have been connected through the power line to a header dPoP located in the same floor and an Ethernet connection has been used to connect the two floors. This setup has been used because the HomePlug AV signals are only able to go beyond a finite number of passive elements, such as circuit breakers and residual-current devices, because they introduce a high level of attenuation. Finally, in order to connect the different dPoP we have used Devolo dLAN 200 AV+ modems, which are fully compatible with the HomePlug AV standards and provide backwards compatibility with HomePlug 1.0.

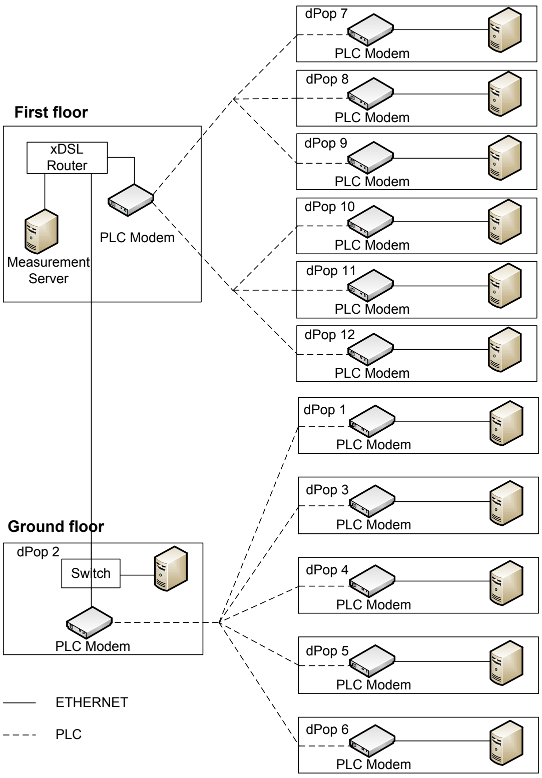

Fig. 3. "*Centre de la Vila*" network topology. Floors are connected through Ethernet to extend the HomePlug AV coverage beyond passive elements, such as circuit breakers and residual-current devices.

In order to evaluate the suitability of the HomePlug AV standard to transmit real-time multimedia data in a shopping mall environment we have carried out different bandwidth measurements using the TCP (Transmission Control Protocol) protocol. Specifically, we have set up a central node, located in the first floor together with the xDSL router, which runs the GNU/Linux operating system and executes a Python script that periodically launches IPerf to measure the available TCP bandwidth with each dPoP. On its behalf each dPoP, which runs an embedded version of Windows XP, executes an IPerf instance as a service to act as a client. Each test to a client lasts for ten seconds, after which the central node stops for ten seconds, and then continues with the following client. Thus, taking into account that there are twelve dPoPs, each complete cycle lasts for 240 seconds. Finally, it is important to mention that the measurements were carried out the last week of July during the time that the shopping mall was open to the public (8:30am – 3:30am, including weekend) and lasted for one full week.

IV. Obtained Results

As described in the previous section, the parameter under study is the TCP bandwidth available to dPoPs through the power line network from the header modem. We choose to study TCP bandwidth as it is the protocol that the proprietary content distribution system uses to transmit the real-time multimedia information over the Internet. Nevertheless, we acknowledge that TCP protocol is not the most suitable to transmit such real-time multimedia information as the TCP congestion control mechanism can have a negative impact on streaming performance due to latency or packet loss.

First we show the instantaneous TCP bandwidth results for dPoP #4 (Figure 4), located on the first floor, and dPoP #8 (Figure 5), located on the second floor, obtained during the eight consecutive days in which the measurements were taken. Here it is important to notice that the TCP bandwidth is mainly stable throughout the daytime, with no outages during the measurement time. Also notice that the downtime is associated to the times that the shopping malls are closed to the public and, thus, the advertising screens are shut down.

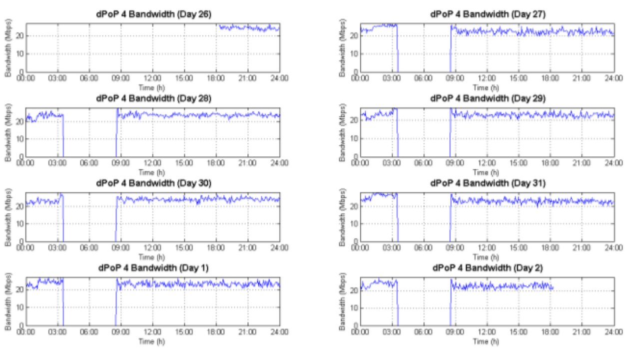

Fig. 4. TCP bandwidth results for dPoP #4.

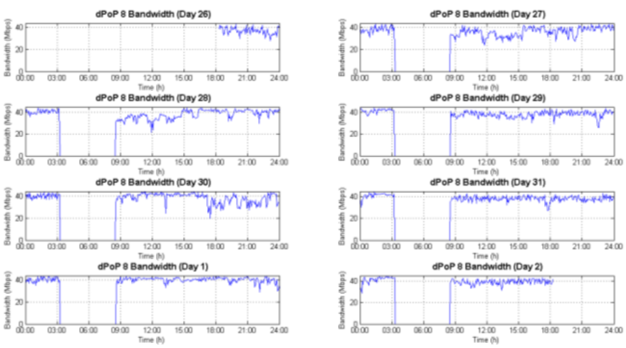

Fig. 5. TCP bandwidth results for dPoP #8

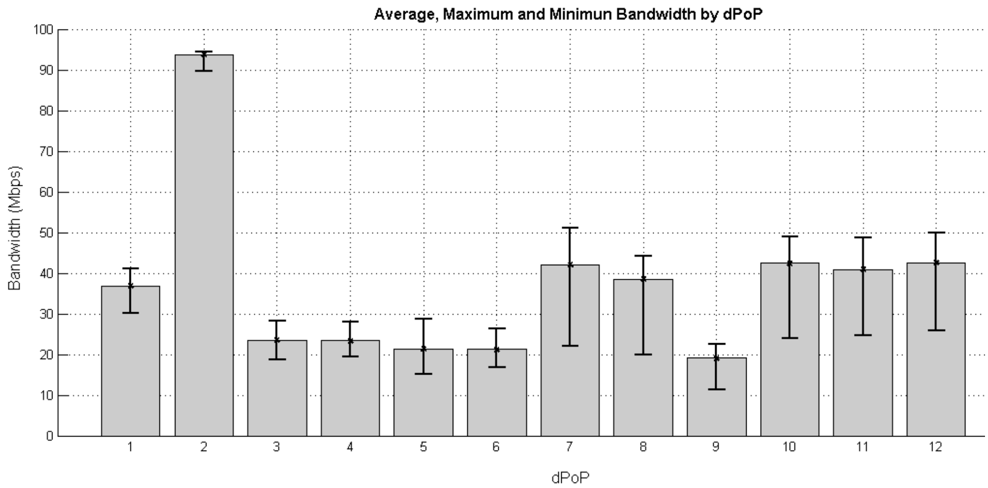

Fig. 5. TCP bandwidth results overview (average, maximum and minimum) for the different dPoPs.

Next, in Figure 5, we show the average, the maximum and the minimum TCP bandwidth values for the different dPoPs deployed at the shopping mall. As it is possible to see, the average TCP bandwidth value lays around 30 Mbps regardless of the time of the measurement. Additionally, it is important to notice that the maximum and the minimum TCP bandwidth values are close enough to the mean, confirming that the network is stable throughout its operation time. For instance, the average TCP bandwidth of dPoP#4 is around 38.5 Mbps, whereas maximum and minimum bandwidth is 44.2 Mbps and 20.0 Mbps respectively. On its behalf, the average TCP bandwidth of dPoP#8 is 23.4 Mbps, whereas maximum and minimum bandwidth is 28.0 Mbps and 19.4 Mbps respectively. Finally, it is important to remark that dPoP #2 is connected using Ethernet and, thus, the obtained results are not directly comparable to the results obtained through the HomePlug AV network.

V. Conclusions

This paper has presented the first results and experiences obtained from deploying a HomePlug AV-based network to distribute real-time multimedia contents in a shopping mall for Digital Out-of-Home (DOOH) Advertising applications.

The results, which are summarized in Table 1, show that the HomePlug AV standard is well for such scenarios despite the adverse operation conditions, e.g. changes in network impedance due to appliances being connected, as well as impulsive and broadband noise coming from lighting and the HVAC system. Nevertheless, even in the worst-case scenario measurements show that the network offers a minimum TCP bandwidth of 10Mbps, which is enough to transmit a real-time video with DVD quality.

Therefore it is possible to conclude that using the HomePlug AV standard in shopping malls for Digital Out-of-Home Advertisement applications makes both technical and economic sense. Not only it offers a sufficient bandwidth to distribute real-time multimedia contents, but it also enables to reuse the existing infrastructure, thus reducing the overall deployment and maintenance costs.

Table 1: TCP Bandwidth summary.

	Bandwidth (Mbps)		
	Mean	***Max.***	***Min.***
dPoP 1	36,9	41,1	30,2
dPoP 2*	93,8	94,3	89,7
dPoP 3	23,5	28,1	18,6
dPoP 4	23,4	28,0	19,4
dPoP 5	21,3	28,6	15,2
dPoP 6	21,2	26,3	16,9
dPoP 7	42,0	51,0	22,0
dPoP 8	38,5	44,2	20,0
dPoP 9	19,1	22,6	11,4
dPoP 10	42,4	49,0	24,0
dPoP 11	40,9	48,6	24,6
dPoP 12	42,6	50,0	25,9

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