Evaluation of a New Proposal for Efficient Multicast Transmission in HomePlug AV Based In-Home Networks*

P.J. Piñero-Escuer, J. Malgosa-Sanahuja, P. Manzanares-Lopez, and J.P. Muñoz-Gea

Department of Information Technologies and Communications, Polytechnic University of Cartagena,
Antiguo cuartel de Antigones, Plaza del hospital, 1, 30202, Cartagena, Spain
{pedrop.escuer,josem.malgosa,pilar.manzanares,juanp.gea}@upct.es

Abstract. With the appearance of P2P networks and the rapid progress in the technologies used to set up in-home networks, these will have an important part to play in the Future Internet and the so-called Information Society. Among the different technologies that could be used to set up an in-home network, PLC (Power-line Communications) is the one that is eliciting most interest in the industry and the scientific community. However, the leader standard in this technology (Homeplug AV) imposes major limitations when it comes to multicast transmissions. Multicast communications are extremely useful in applications which are especially popular in in-home networks so this paper proposes a new method for implementing multicast transmissions in HPAV networks.

Keywords: In-home Networks, Powerline Communications, Homeplug AV, Multicast.

1 Introduction

Nowadays, home appliances are not stand-alone things anymore. They are becoming information appliances which can be networked to exchange their information. Therefore, it is necessary a home network (also called in-home or in-building network) able to provide support for multimedia and data transmission from a variety of sources in the home. There are currently several alternatives that could be used to set up an in-home network. Among these technologies, PLC (Power-line Communications) has recently elicited much interest between the industry and the scientific community [1]. This interest is mainly because

* This research has been supported by project grant TEC2010-21405-C02-02/TCM (CALM) and it is also developed in the framework of "Programa de Ayudas a Grupos de Excelencia de la Región de Murcia, de la Fundación Séneca, Agencia de Ciencia y Tecnología de la RM (Plan Regional de Ciencia y Tecnología 2007/2010)". Pedro J. Piñero-Escuer also thanks "Fundación Séneca" for a FPI pre-doctoral fellowship. (Exp. 13251/FPI/09).

M.L. Reyes et al. (Eds.): IT Revolutions 2011, LNICST 82, pp. 58–70, 2012.

networks that use PLC technology are easy to install and expand as they use the low-voltage wiring installed in the building.

There are different PLC technology standards, but the most popular is HomePlug AV (HomePlug Audio and Video, or simply HPAV). This standard, which was presented by Homeplug Powerline Alliance [2] in 2005, can supply transmission rates of up to 200 Mbps over low-voltage wiring in any building. Moreover, there are over 70 certified Homeplug products on the market at this time, including products that expand this technology, achieving transmission rates of up to 1Gbps [3].

One of the main problems of using HPAV to widespread an in-home network is that IP multicast communications are not possible with the present standard. The reason is that although the PLC channel is broadcast, the OFDM modulation used on the physical layer is point-to-point. The technique used for transmissions to a set of receivers in HPAV networks is to send each package to the various members of the group consecutively using point-to-point transmissions. With this technique the effective transmission capacity deteriorates rapidly as the number of customers increases. This problem has to be solved in next versions of the standard because IP multicast technology can be very helpful in some of the more common applications of in-home networks, like networked games or multimedia content transmissions among several users. This paper proposes a new way of implementing multicast communications over HPAV networks, which achieves high transmission rates even when the number of multicast group members is very large. The proposed method is evaluated in both physical and MAC layer through the simulation models proposed in [4] and [5][6] respectively.

The remainder of the paper is organized as follows: section 2 describes the main characteristics of the HomePlugAV technology. Section 3 presents the proposed multicast technique, which is carefully evaluated in section 4. In that section, the PLC simulators employed in this work are also described. Finally, section 5 summarizes the main conclusions of the research.

2 Homeplug AV Technology

Homeplug AV (HPAV) is a standard developed by the Homeplug Powerline Alliance with the purpose of providing enough capacity to support broadband Internet access and the distribution of high-quality audio and video contents. In order to achieve these objetives this standard employs advanced PHY and MAC technologies which are described in the following subsections.

2.1 Physical Layer

The Physical Layer (PHY) operates in the frequency range of 2 - 28 MHz. It uses Orthogonal Frequency Division Multiplexing (OFDM) [7] and a powerful Turbo Convolutional Code (TCC). OFDM modulation is based on simultaneous transmission of a large number of orthogonal carriers to one another with a very narrow bandwidth. Specifically, 1,155 carriers from 1.8Mhz to 30Mhz are used

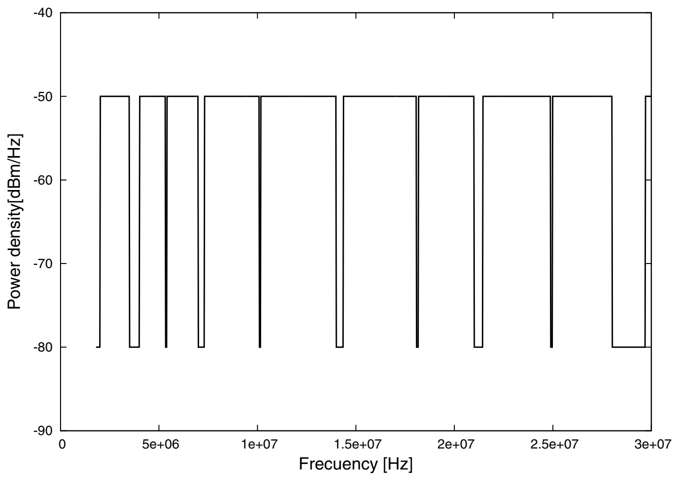

Fig. 1. HomePlug AV transmission mask

in HPAV, so that the separation between carriers is approximately 24.4KHz. However, some of these carriers coincide with radio amateur emission bands and cannot be used, which brings the total of usable carriers down to 917. Figure 1 shows the attenuation mask that has to be used on HPAV transmissions to eliminate unavailable frequencies in the 1.8-30 Mhz range. As the figure also shows, the transmission power of the usable carriers is limited to -50dBm/Hz.

Depending on the characteristics of the channel that the transmitter detects, it selects the appropriate modulation and coding for each carrier. This modulation may be anything from simple BPSK (1 bit of information per carrier) when the SNR is low, to 1024 QAM (10 bits of information per carrier) when the SNR is very high (see table 1 [8]). The choice of modulation will differ depending on the desired bit error probability. It is also important to note that any carrier will be eliminated if its SNR is lower than the minimum required by the BPSK modulation.

Each modem connected to the network has a Tone Map (TM) to communicate with the others which indicates the type of modulation and codification that each carrier has to use. It is important to realise that, due to the properties of the PLC channel, its frecuency response for each transmitting-receiving pair will be different, and as a consequence, the TM will be different too. Therefore, although the PLC channel is broadcast, with OFDM modulation communications are always point-to-point and each transmitting-receiving pair will have a different transmission rate.

To obtain the tone maps the transmitter invokes a channel estimation procedure which can be divided into two phases:

- Initial channel estimation
- Dynamic channel estimation

Table 1. HPAV System parameters

PHY LAYER		MAC LAYER	
Number of carriers	917	max_FL	2501.12 μsec
Bandwidth	2 - 28 MHz	HPAV Head Time	110.48 μsec
	BPSK (12-15 dB)	Response Timeout	140.48 μsec
	4-QAM (15-20 dB)	RIFS	100μs
	8-PSK (20-22 dB)	CIFS	30.72μs
Modulation for 10^{-8} BER	16-QAM (22-29 dB)	PRS0	35.84μs
(SNR Range)	64-QAM (29-35 dB)	PRS1	35.84μs
	256-QAM (35-40 dB)	PB size	520 bytes
	1024-QAM (>40 dB)		
Symbol Duration + GI	46.52 μs		
Max. Power	-50dBm/Hz		
FEC Information Rate	16/21		

The transmitter invokes the initial channel estimation procedure when it needs to transmit data to a destination and it does not have any valid tone map. During this procedure the transmitter sends one or more frames to the receiver, who uses them to estimate the channel characteristics and designate a Default Tone Map. This tone map may be used by the transmitter anywhere in the AC line cycle. Then the receiver sends this tone map back to the transmitter.

Once the transmitter have a valid tone map, it starts to transmit data frames to the receiver. Using these data frames, the receiver is able to provide updates to the default tone map or new tone maps that only are valid at specific intervals of the AC line cycle. This procedure is called dynamic channel estimation.

The maximun number of tone maps for a particular transmitter-receiver pair is established by the Homeplug AV standard and is limited to seven.

2.2 MAC Layer

HomePlug AV standard provides two kinds of communication services:

- Connection-oriented contention free service, based on periodic Time Division Multiple Access (TDMA) allocations of adequate duration, to support the QoS requirements of demanding applications
- Connectionless, prioritized contention service, based on CSMA/CA, to support both best-effort applications and applications that rely on prioritized QoS.

To efficiently provide both kinds of communication service, HomePlug AV implements a flexible, centrally-managed architecture. The central manager is called a Central Coordinator (CCo). The CCo establishes a beacon period and a schedule which accommodates both the contention free allocations and the time allotted for contention-based traffic.

2.3 Multicast Communications in HPAV

Because of the characteristics described above, implementation of multicast transmissions on HPAV networks presents serious problems. The use of IP multicast technology in HPAV networks automatically translates into a consecutive series of point-to-point transmissions to each member of the multicast group (this is done in a way that is totally transparent to the user). In this way the effective multicast transmission capacity can be calculated by means of equation (1).

$$\frac{1}{C_{total}} = \sum_{i=1}^{N} \frac{1}{C_i} \tag{1}$$

Complementing OFDM modulation, the HPAV standard uses a special type of modulation called ROBO (ROBust Ofdm), which permits broadcast transmission. This transmission mode is used whenever it is necessary to transmit control packages (or any other kind of broadcast package) that has to be received by all members of the HPAV network. The ROBO mode uses robust anti-noise modulation and coding to assure proper reception and decoding of information in all receivers. This might seem a good transmission mode for multicast communications; however, the transmission rate of the ROBO mode is limited to around 5-10 Mbps (10 Mbps mode is only availabe if channel conditions are optimal between all the modems), which could be inadequate for the majority of multicast applications.

3 Proposed Multicast Technique

The research presented in this article proposes an alternative solution for multicast communications over HPAV networks. The multicast transmission mode proposed here consists in choosing and using a common tone map for all members of the multicast group. In this common tone map each carrier will be assigned the modulation corresponding to the multicast group member with the worst SNR for this frequency. In this way, all the members of the multicast group will be able to decode the information properly because the number of bits of information in the modulation chosen for each carrier will be equal to or less than the number that would be assigned to a point-to-point transmission.

This transmission mode presents an important advantage over the traditional HPAV multicast system because the number of members of the multicast group do not significantly affect the effective capacity of the multicast transmission. Although this technique has been proposed for other technologies that employ OFDM modulation, it has never been evaluated over HPAV scenarios.

3.1 Channel Estimation Procedure Modification

In the proposed multicast technique, the multicast tone map has to be transmitted to the multicast clients after being calculated by the transmitter. For this reason, a modification of the channel estimation procedure is needed.

To simplify, only default tone maps are taken into account in this work because, if more tone maps are considered, the procedure complexity considerably increases. The design of a procedure able to manage all the tone maps is considered as the next step in this research work. With these assumptions, the modified channel estimation procedure is divided into four steps:

1. Before starting the multicast communication, the transmitter must have the default tone map of all the multicast receivers. If this is not the case, initial channel estimation procedure must be started. This step is also performed in the original multicast technique.
2. After collecting all the tone maps, the multicast tone map is estimated by selecting for each OFDM tone the most restrictive modulation.
3. The estimated tone map is transmitted to the multicast clients.
4. When any update of a tone map is received, the multicast tone map has to be re-calculated. In this case three situations may happen:
   - The multicast tone map does not change.
   - The amount of bits in one or more carriers of the multicast tone map diminishes. In this case the new multicast tone map has to be transmited to the multicast clients.
   - The multicast capacity increases. In this case the new tone map is only transmited to the clients if the improvement in the transmission capacity is significant (eg. more than 10%)

With this new channel estimation procedure a very low overhead is introduced, because the multicast tone map has only to be transmited on a very few occasions.

4 Evaluation

The proposed multicast technique has been evaluated at physical and MAC layers. The simulators employed in this work has been previously proposed in prestigious specialized journals, and they are carefully described in the following sections.

4.1 PHY Layer Simulator

To check the proper functioning of the proposed multicast transmission mode the PLC channel frecuency response between every transmitting-reciving pair is needed in order to obtain the physical transmission rate between each pair. To obtain this response, a PLC channel simulator based on the model proposed in [4] was developed. According to that paper, the PLC channel could be described as a LTI (Linear Time Invariant) system or as a LPTV (Linear Periodically

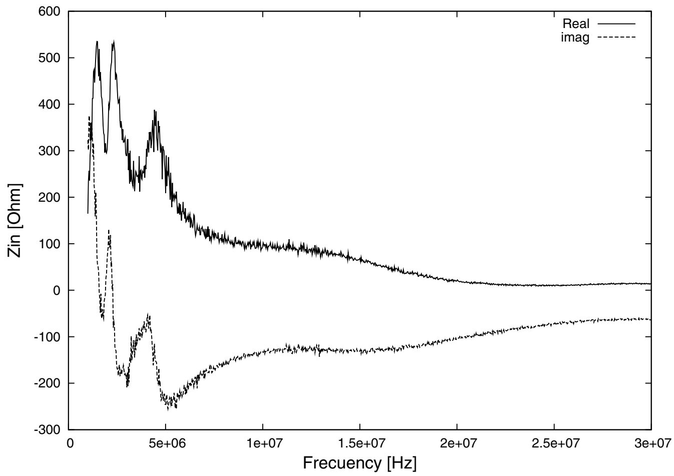

Fig. 2. Input impedance of HPAV Linksys PLE200 modem

Time Varying) system. To simplify, LTI model has been employed. Although this supposition is not entirely correct, the error it entails does not substantially affect the results analysed in this study. Moreover, since only default tone maps are taken into account, the use of the LPTV model is not neccesary.

The model assumes that the electrical wiring consists of a set of interconnected twin-core transmission lines conforming a tree-shaped topology. At the ends of these lines there may be an open circuit or a device. The devices are characterized as 2-terminal circuits with a linear load and a noise source. Finally, the transmitter and receiver are also composed of a linear load, as well as a signal generator in the case of the transmitter. Therefore, to be able to simulate the behaviour of a device connected to a socket we need to know its characteristic impedance and the power spectral density (PSD) of the noise that it generates. In this study we have characterized some of the more common household devices (mobile phone charger, hair dryer, lamps, etc) and the Linksys model PLE-200 HPAV modem. Figure 2 shows the real and the imaginary part of the modem input impedance.

The channel response between any two points in the network will be determined not only by the distance between them but by the impedance of the different ramifications of the power network that do not belong to the main pathway between the transmitter and the receiver. The mode to which the main pathway is affected by these impedances can be calculated by applying the properties of the transmission lines.

Finally, the noise in the receiver can have one of two possible sources: external to the network or generated by the devices. In the second case a device contribution to the total noise will be determined by the channel response from the device to the receiver. The total amount of noise is calculated using the superposition principle.

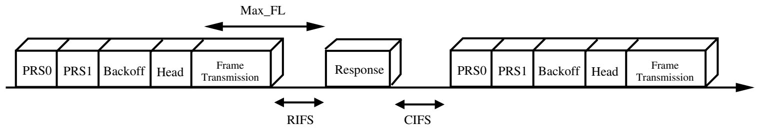

Fig. 3. Timing sequence on medium

Once the frecuency response between each pair is obtained, the number of bits per carrier can be obtained using the modulation scheme showed in table 1. Knowing the number of bits per carrier, the physical capacity of the link can be calculated by dividing the number of bits per symbol by the period of each OFDM symbol (i.e. 46.52μs with the guard interval). Finally, the real physical information rate can be calculated by multiplying this value by the FEC information rate (i.e. 16/21).

4.2 MAC Layer Simulator

Although, according to the standard, HomePlug AV provides two kinds of communication services, most of HPAV modems only implements connectionless CSMA/CA service. For this reason, the MAC layer simulator used in this work only implements this service.

Homeplug AV CSMA/CA protocol uses priority resolution and random backoff in order to resolve collisions efficiently and provide QoS. Each transmission is predeced by two priority resolution slots called PRS0 and PRS1. There are also two gaps, one after a succesful transmission and another before the reception of the response, called CIFS and RIFS respectively. Table 1 shows the values employed in this work for these parameters and figure 3 shows an example of timing sequence for the transmission of frames on the medium. An important restriction on the sequence is the parameter Max_FL, that cannot be longer than 2501.12μsecs. Therefore, the amount of bytes transmitted by a station depends on its physical rate. In addition, this quantity must be multiple of the physical block (PB) length.

The main properties of the CSMA/CA protocol used in Homeplug 1.0 and Homeplug AV are explained in [5] and [6]. The authors of that work develop a protocol model using a tridimensional Markov chain. A method to obtain the throughput and the MAC delay is also explained. However, the main problem of this analysis is that all the physical transmission rates between the transmitter-receiver pairs are assumed to be the maximum allowed transmision rate. In order to use this simulator together with the PHY simulator, a modification that permits different transmission rates among the stations was done.

4.3 Simulation Scenario

To evaluate the proposed multicast technique, a typical in-building scenario is considered. This scenario is composed of two homes which share the same electrical phase. The homes used in the simulation are shown in figure 4. In this

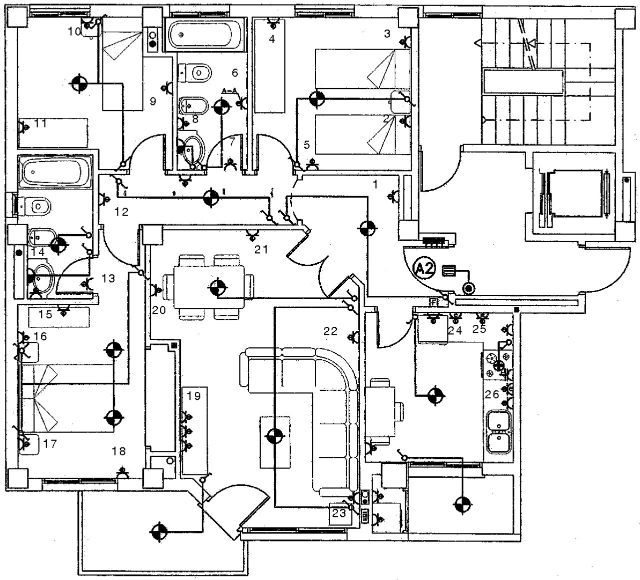

Fig. 4. Plan of the homes used in the simulation

plan, all the sockets available in each home are numbered from 1 to 26 and lighting points are marked with a two-colour circle. There are ten HPAV modems connected to the sockets 4A (i.e. socket 4 in home A), 9A, 17A, 19A, 24A, 3B, 11B, 18B, 19B and 21B. There are also some home appliances connected to the other sockets.

4.4 Results

In the first simulation all the HPAV modems are supposed to belong to the same multicast group. In this case the server is placed in the socket 4A and it transmits information to the other members of the multicast group. Figure 5 shows the SNR of the channel linking each transmitter-receiver pair. The figure also shows the minimum SNR for each carrier. These values and the OFDM modulation scheme used by HPAV are employed to calculate the physical channel capacities in each case. Once the point-to-point capacities between the different devices are known, the traditional multicast transmission capacity can be determined using equation (1) and, as can be seen in table 2, it is approximately 11 Mbps. However, the multicast transmission capacity of the model proposed in this paper is calculated by applying the same modulation scheme to the minimum SNR in each carrier (also marked in the graph by a heavier line), and its value is slighter greater than 68 Mbps. With this results it can be seen that the channel capacity obtained with the proposed method is much greater (approximately 6 times) than the capacity achieved with the traditional method used in HPAV devices.

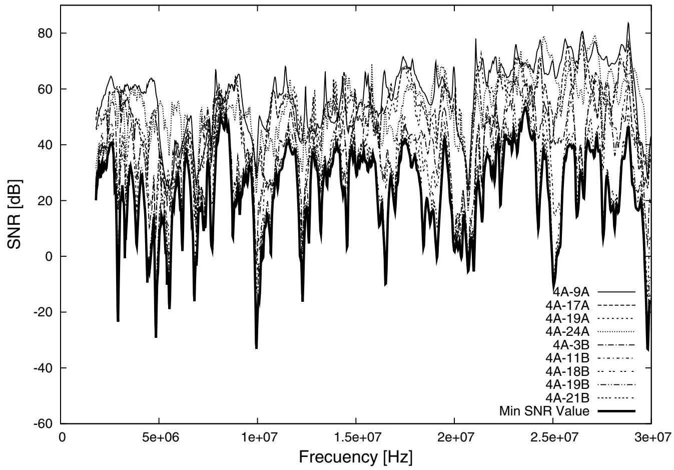

Fig. 5. Point-to-point transmissions signal-to-noise ratio

Table 2. Physical evaluation of the proposed multicast method

Link	C (Mbps)
4A - 9A	146.380
4A - 17A	141.784
4A - 19A	142.767
4A - 24A	143.554
4A - 3B	115.367
4A - 11B	103.673
4A - 18B	76.763
4A - 19B	77.025
4A - 21B	74.067
Point-to-Point Multicast	11.671
Proposed Multicast	68.459

It should be interesting to study how the multicast capacity evolves when the clients are added successively to the multicast group. The multicast capacity values of the two techniques are showed in Figure 6. In this case, the clients have been added to the multicast group in the order showed in table 2. Note that the multicast capacity of the proposed method is higher than the value obtained through the point to point method independently of the number of clients.

It is also important to remark that the multicast values will depend on the client connection order. However, independently of the connection order, the capacity obtained by using the proposed method will always be higher than the capacity obtained with the point-to-point method.

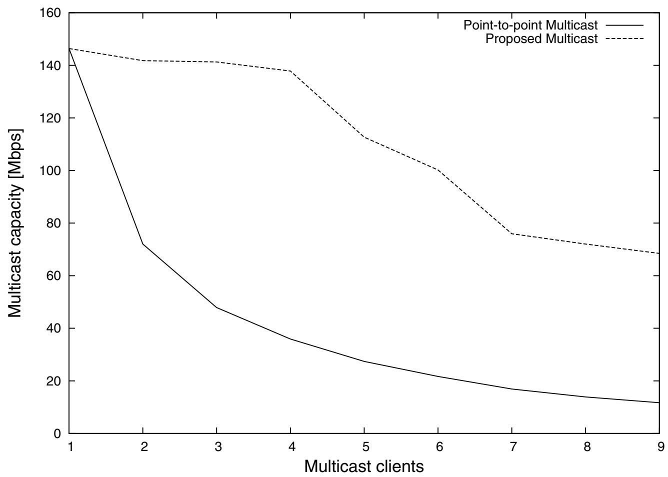

Fig. 6. Evolution of multicast capacity as a function of the number of clients for the two multicast methods under study

To evaluate the MAC layer behaviour of the proposed multicast method, an scenario with six multicast group members was considered. In this scenario the server is placed in the socket 4A and it transmits some information to the other members of the multicast group (sockets 9A, 19A, 24A, 11B and 18B). In this simulation, it is assumed that besides the multicast session, there are also a set of background conecttions (all of them independent of the multicast session) competing for the channel. For that reason, there are only five clients in the multicast group and the rest of modems are used to generate those background connections. In this case, the physical multicast capacity obtained through the proposed multicast method is 76.157, while the capacity obtained through the point-to-point method is 23.002 (more than three times worse).

The multicast MAC throughput has been evaluated as the number of stations that contend for the channel with the multicast server grows. The results are shown in figure 7. This figure has been represented with logaritmic axes to clearly see the differences between both techniques. The simulations were made under saturated conditions (i.e. all the stations have frames for transmitting immediately after the successful completation of a frame transmission).

Note that the amount of bytes per second that each client receives with the point-to-point method depends on its physical unicast capacity. Therefore, there are more than one alternative to calculate the MAC multicast throughput. One of them (maybe the most representative) is to transmit a big file (200 MB it is enough) and measure the time elapsed in the file transmission. Due to the channel capacity mismatch, the server stops sending packets to a client when it has received the entire file. The multicast file transmission ends when all the clients have completely received the file.

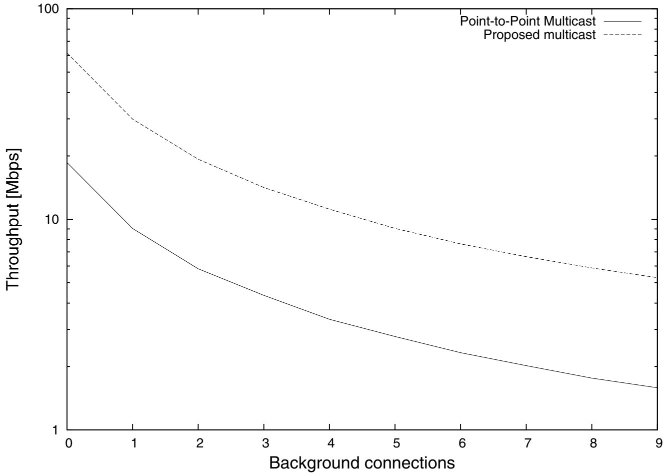

Fig. 7. MAC layer evaluation of proposed multicast technique

From the results showed in the figure, it could be seen that when there is not contending stations the proposed method throughput is 61.65 Mbps while in the point-to-point case it is 18.596 Mbps. Note that, in both cases, the throughput is reduced by 19% regarding to the physical capacity due to the time wasted in the priority resolution slots and in the backoff procedure. In the figure it also can be seen that the difference between the proposed multicast method and the traditional point-to-point multicast method remains constant as the number of contending stations grows. This result is because the MAC delay value depends on the number of stations that contends for the channel and, although the number of channel accesses of the multicast server with the point-to point method is higher, the real number of stations is the same in both cases, since multicast clients never issue a frame (i.e., they are only receivers).

5 Conclusion

The use of PLC technology for deploying in-home or in-building networks, in particular using the HPAV standard (the leader in this technology) imposes major limitations when it comes to multicast transmissions. Multicast communications are extremely useful in applications which are especially popular in in-home networks, so this paper proposes a new method for implementing multicast transmissions in HPAV networks.

The functioning of the proposed multicast method has been checked in both physical and MAC layers. The results show that the characteristics of the proposed method are a very great improvement on the point-to-point transmission method and achieves physical transmission capacities which are several times greater than can be achieved with point-to-point transmissions.

This research also has some future work to be done. The more important points of this future work are:

– Evaluate the proper functioning of the proposed multicast technique when a LPTV channel model is employed.
– Design a tone map exchange protocol able to manage the seven tone maps which can be employed in each unicast communication.

Finally, this article also intends to be used as a guide of how to design a multicast protocol for the Homplug AV standard, because in it solutions for some of the more important problems of this design are presented (variable capacity of the physical links, tone maps exchange protocol, etc). Moreover, the presented results can be employed to check the improvements presented by new multicast protocols in the near future.

References

1. Afkhamie, K.H., et al.: An overview of the upcoming HomePlug AV standard. In: Power Line Communications and Its Applications, ISPLC 2005, pp. 400–404 (2005)
2. Homeplug Powerline Alliance, `http://www.homeplug.org`
3. Gigle semiconductors (2009), `http://www.giglenetworks.com/`
4. Sancha, S., Canete, F.J., Diez, L., Entrambasaguas, J.T.: A Channel Simulator for Indoor Power-line Communications. In: IEEE International Symposium on Power Line Communications and Its Applications, ISPLC 2007, pp. 104–109 (2007)
5. Chung, M.Y., Jung, M.-H., Lee, T.-J., Lee, Y.: Performance analysis of Home-Plug 1.0 MAC with CSMA/CA. IEEE Journal on Selected Areas in Communications 24(7), 1411–1420 (2006)
6. Yoon, S.G., et al.: Adaptive Contention Window Mechanism for Enhancing Throughput in HomePlug AV Networks. In: CCNC 2008, pp. 190–194 (2008)
7. Bahai, A.R.S., Saltzberg, B.R., Ergen, M.: Multi Carrier Digital Communications: Theory and Applications of OFDM. Springer, New York (2004)
8. Homeplug AV Specification. Homeplug Alliance (December 2005)