A Performance Study of EY-NPMA for Medium Access in Power Line Communications

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Abstract

Power Line Communications provide an efficient and inexpensive way for the creation of access or in-house networks, especially in areas where there is no dedicated pre-existing cabling for communications. The choice of a suitable medium access scheme is imperative, since the MAC is the final arbiter of the efficient usage of the available network resources or not. In this paper we present a modified version of the EY-NPMA medium access scheme for power line communications, showing through simulation trials the very good characteristics of the proposed scheme.

1. Introduction

Power Line Communications (PLC) are expected to play a major role in access and in-house networks in the near future. The growing demand for broadband access to the Internet, as well as the trend for home automation and digital entertainment has triggered intense research on the field, as well as other alternative means for providing broadband communication capabilities to the general public. A very desirable attribute of power line communications is that PLC provide an efficient and inexpensive way for the creation of such networks, without the demand of installing new cables or retrofitting. During the last few years, a lot of research has been conducted in the field, mostly focusing in the physical layer. However, the careful choice of a medium access control scheme that is suitable for power lines is very important, since the MAC is the final arbiter of the efficient usage of the available network resources or not. In this paper we present and evaluate the performance of a modified version of the EY-NPMA medium access scheme for power line communications, a protocol which is part of the HIPERLAN [1] wireless networking standard. The rest of the paper is structured as follows. In section 2, we provide a detailed description of the proposed medium access scheme, while in section 4 we present and comment the performance results that were acquired through simulation trials. Finally, section 5 concludes the paper.

2. Background Work

A medium access scheme must fulfill three requirements in order to be an efficient one. It must ensure that the common medium is fairly shared between the terminals that participate in the network, provide quality of service (QoS) guarantees for different classes of traffic and finally minimize the wasted capacity caused by collisions and/or overhead. Furthermore, all of the above should lead to a design that is both robust and easy to implement.

Medium Access protocols may be categorised into three classes, depending on the paradigm that each terminal follows to acquire access to the shared medium. With fixed assignment protocols (e.g. TDMA) a constant portion of the total capacity is allocated to each terminal a priori, regardless of how each terminal’s traffic pattern varies. This proves to be especially inefficient in cases of bursty traffic, which is the case in Internet applications. When a station has no data packets to transmit, the allocated bandwidth is simply wasted.

With contention based medium access schemes, each terminal attempts to gain access to the shared medium, only when there is data to transmit. Transmissions are not coordinated and are scheduled in a totally distributed way, hence there exists a possibility that two or more terminals transmit simultaneously, leading to packet collisions. Carrier sensing plays a key role in protocols following this paradigm, a feature that allows terminals to refrain from transmitting, when they sense that a transmission is already in progress. Generally, contention based schemes are particularly well suited for bursty traffic, but their efficiency deteriorates rapidly when the offered load exceeds a certain threshold. Furthermore, most protocols belonging to this class do not provide
support for quality of service. Medium access schemes that are based on contention are ALOHA, CSMA and all its variants (CSMA/CD, CSMA/CA, CSMA/OD...).

The third category of Medium Access protocols consists of those that are based on dynamic assignment. All medium access schemes following the dynamic assignment approach gain access to the common medium either via an arbitrator (e.g. a terminal that polls each station in a round-robin fashion) or through a well-defined process that ensures that only one terminal at a time has permission to gain access to the channel (e.g. token passing schemes). Compared to contention based medium access schemes, the performance of dynamic assignment protocols does not deteriorate when the traffic load increases. On the other hand, the fact that each station must explicitly acquire access permission (i.e. get polled or capture the token), introduces a latency that is mostly notable in cases of light traffic. Furthermore, traffic load asymmetries tend to deteriorate the performance of these protocols. Of course, besides the protocols that purely belong to one of the three aforementioned families, there is a number of hybrid protocols that combine elements of protocols belonging to different classes.

The medium access protocols that have been proposed for powerline communications are mostly based on the dynamic assignment paradigm [2]. The fact that the major application envisaged for powerline communications is the cost efficient creation of access networks makes such a choice suitable, where the management entity (Base Station) is placed on the LV/MV transformer. The biggest shortcoming of contention based protocols, the increasing rate of collisions as traffic becomes heavier, has discouraged network designers into proposing it as a solution for an access network, since the limited channel capacity and large population of stations (in the order of hundreds) would lead to unacceptably low levels of throughput. In the case of in-home networks, however, contention based protocols provide a better solution, since they have to deal with a limited population of stations and do not demand a network management entity that must always be on-line.

The communications environment of powerline communications has many elements in common with that of wireless LANs. A medium of limited capacity is shared by a large population of stations, while both kinds of networks show some resemblance on the physical layer, since in both cases transmissions are grievously plagued by noise and high delay spread. The intense research of the last years in the field of wireless networks has led to medium access schemes that quickly were adapted and proposed for PLCs [3][4]. CSMA/CA which is the heart of the DCF (Distributed Coordination Function) access mode of the 802.11 standard for wireless LANs, as well as the medium access protocol of the Bluetooth standard have been proposed and evaluated for PLCs. In this paper we describe and measure the performance of a modified version of the EY-NPMA medium access scheme, a random access scheme which proves to perform very well either on the access loop or on in-home networks.

3. Protocol Model

EY-NPMA stands for Elimination-Yield Non-preemptive Priority Multiple Access. It is a contention based protocol that has been standardised under ETSI’s HIPER-LAN, a standard for wireless LANs. Unlike other contention based protocols, EY-NPMA provides excellent support for different classes of traffic regarding quality of service and demonstrates very low collision rates. With EY-NPMA, each station may attempt to access the channel when a condition out of a group of three is met. The three conditions are: channel free condition, synchronized channel condition and hidden elimination condition. Throughout this paper, we assume that there are no hidden nodes in a PLC communications environment. Consequently, a station may attempt to access the shared medium only when one of the two first conditions is met.

The channel free condition occurs when the channel remains idle for at least a predefined time interval. A station willing to transmit senses the channel for this time interval, which is the same for all stations participating in the network. If no transmissions were detected during this interval,
the station extends its period of sensing by a random number of slots (backoff). If the channel is still sensed as idle during the backoff period, the station commences transmitting. In both modes of operation unicast transmissions must get positively acknowledged or else the transmission is declared erroneous. Multicast and broadcast packets are not acknowledged.

The synchronized channel condition occurs when the channel is idle in the channel synchronization interval, which starts immediately after the end of the previous channel access cycle. The synchronized channel access cycle consists of four distinct phases: Prioritization, Elimination, Yield and Data Transmission. In prioritization, EY-NPMA recognizes five distinct priorities from 0 to 4, with 0 being the highest priority. The cycle begins with each station having data to transmit sensing the channel for as many slots as the priority of the packet in its buffer. All stations that successufully sense the channel as idle for the whole interval proceed to the next phase, the elimination phase. Those that do not, exit the contention process and wait for the next synchronized channel condition to make another attempt. During the elimination phase, each station transmits an energy burst of random length. These bursts ensure that only the stations having the highest priority data at a time proceed to the elimination phase. The length of the energy burst is a multiple of slots up to a predefined maximum. As soon as a station finishes bursting, it immediately senses the channel. If the channel is sensed as idle, the station proceeds to the next phase. Otherwise, it leaves the cycle. During the yield phase, the station that survived the two previous ones, back off for a random number of slots. The station that backs off for the shortest interval eventually gets access of the channel for data transmission. All other station sense the beginning of the transmission and refrain from transmitting. In figure 1, we present a typical synchronized channel access cycle. Solid line boxes represent actual transmissions, while dashed line boxes represent projected transmissions that did not take place because the station left the contention process. The X marks show when and why a station left the cycle.

Through this four-phases cycle, EY-NPMA manages to provide a low and quasi-constant rate of collisions, independent of the number of contending nodes, up to a predefined maximum. Each phase reduces the number of stations that remain into the contention process, so that (hopefully) the station that will commence transmitting data in a given time will be unique. The rate of collisions depends on the maximum number of slots allowed for bursting (elimination phase) and backoff (yield phase). For power lines access networks, however, the population participating in the network may be as high as 400 terminals. A big number of maximum slots for elimination and yielding is demanded, so that the collisions rate remains low. Doing so, however, results in a waste of communication resources, since for the same data packet the access cycle becomes longer. To alleviate this problem, we propose a modification to the base EY-NPMA access protocol that cuts down the number of collisions, while introducing minimal overhead through extra slots.

Our proposed medium access scheme features a different structure for the prioritization phase and a mechanism for dynamically promoting the packet priority for packets that have survived the elimination process, but did not survive the yield phase. Instead of 5 priority classes, we propose a scheme with 4 priorities. The three lower ones consist of two subclasses, namely a low and a high. The structure of the prioritization slots for the two schemes is depicted in figure 2. A data packet of priority $x$ that is placed in the transmission buffer of the MAC controller by an upper layer is automatically labeled as being $x$-low priority. Let $x$-low be the highest priority when a channel access condition occurs and a number of $N$ stations enter the contention process with all $N$ stations commencing bursting at the same slot. At the end of the elimination phase, a fraction of the initial population, $N_s$, will have survived elimination and will choose a random number of slots to backoff. At this point all $N_s$ stations switch their packets priorities from $x$-low to $x$-high. At the next channel access cycle, through the prioritization phase only the $N_s$ stations will enter the elimination phase, in contrast to the at least $N-1$ stations that would enter contention according to the base EY-NPMA scheme. Access cycles at $x$-low priority will be postponed, until there are no more $x$-high packets, which will happen at the end of at least $N_s$ cycles. When there are no more packets of $x$-high priority, an access cycle of $x$-low will follow, and the whole process will be repeated.

Consequently, when a big population of stations wants to send data in the same base priority class $x$, according to the base EY-NPMA scheme in each access cycle this big population will contain for channel access. On the contrary,
with our modification the whole population contents for one cycle, while for a number of subsequent cycles only a subset of these stations will participate in the contention process. Consequently, the proposed scheme leads to much lower collision rates, at the cost of one less priority class and the addition of two extra slots for prioritization. Furthermore, the protocol’s behaviour to the base priority classes does not change by our modification. That is a priority 3 packet will always be of lower priority than a priority 2 packet, no matter what subclass – low or high – the packets happen to be.

4. Simulation

4.1. Simulation Scenario

All the simulations that were conducted to evaluate the performance of the base EY-NPMA scheme, as well as the proposed medium access protocol used a custom simulation tool developed by the authors in C++. Regarding the channel modelling, we assumed that coding and error correction techniques mitigate all channel problems, except the high-energy impulsive noise that garbles all transmissions and renders the channel unavailable for a time interval. We modelled the channel state as a Markov chain with two states, one when the channel is disturbed and the other when the channel is free of noise. Transitions from one state to the other follow a poisson distribution [5]. We defined three noise scenarios, summarised in Table 1.

Table 1: Noise Scenarios

<table>
<thead>
<tr>
<th>Noise scenario</th>
<th>Impulse Inter-arrival Time</th>
<th>Impulse duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>∞</td>
<td>0</td>
</tr>
<tr>
<td>Light</td>
<td>300 ms</td>
<td>5 ms</td>
</tr>
<tr>
<td>Heavy</td>
<td>100 ms</td>
<td>20 ms</td>
</tr>
</tbody>
</table>

4.2. Simulation Results

In our experiments, the network consists of 200 stations sharing the same common medium. Out of these 200 stations, 40 generate high priority traffic, while the rest of the population generates low priority traffic. High priority sources generate packets with a rate that is 5 time higher than that of low priority sources, while the packet length is the same for both cases and equal to 500 bytes. So, at any given traffic load 45% is due to low priority sources and 55% is due to high priority sources. Table 2 summarises some of the other parameters that were used for the simulations.

Table 2: Simulation Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Channel Capacity</td>
<td>1 Mbps</td>
</tr>
<tr>
<td>Max Elimination Slots</td>
<td>6</td>
</tr>
<tr>
<td>Max Yield Slots</td>
<td>6</td>
</tr>
</tbody>
</table>

In our experiments, the network consists of 200 stations sharing the same common medium. Out of these 200 stations, 40 generate high priority traffic, while the rest of the population generates low priority traffic. High priority sources generate packets with a rate that is 5 time higher than that of low priority sources, while the packet length is the same for both cases and equal to 500 bytes. So, at any given traffic load 45% is due to low priority sources and 55% is due to high priority sources. Table 2 summarises some of the other parameters that were used for the simulations.
We note that in the case of the base EY-NPMA scheme, there are two steep falls in throughput. The first one occurs when the network becomes saturated and cannot cope with the increasing traffic. At this point, the collision rate between low priority packets increases abruptly and throughput decreases sharply. The second point occurs when the same thing happens to high priority packets. On the other hand, in the proposed scheme’s results this phenomenon occurs only in the case of high priority packets and then in a much smaller scale. Generally, the proposed protocol shows a better behaviour than the base EY-NPMA scheme, leading to increases in throughput ranging from 5% to 10%.

Figures 5 and 6 depict the mean delay values for both schemes. The two sharp rises in delay in both figures correspond to the aforementioned points where the system cannot cope with the offered load and collisions start to occur. As hinted by the throughput figures, in the case of the base EY-NPMA scheme these sharp rises occur earlier than in the case of the proposed scheme. Also, eventhough the modified EY-NPMA scheme achieves greater values of throughput, the mean packet delay is actually lower. For maximum offered load, high priority packets show a delay of 183 ms in the case of the proposed scheme versus 195 ms in the case of the base EY-NPMA medium access protocol.

5. Conclusions

In this paper we tested and evaluated the performance of the EY-NPMA medium access protocol for Power Line Communications. Eventhough it is a contention based protocol, EY-NPMA shows good characteristics that are untypical of a protocol belonging to this paradigm. Quality of Service guarantees and high throughput values even at heavy offered load make EY-NPMA a good solution for PLCs, both for access and in-house networks. Furthermore, we proposed a modification to the base EY-NPMA scheme that enhances the performance, both in terms of collisions rate and delay, incurring minimal cost. The proposed modification proves to be especially positive in the case of access networks, where a large population of stations content for channel access.

References