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Modelling of part medium access methods in the HomePlug

Abstract. *This paper introduces the modeling of HomePlug technology which it is the most extended broadband technology for powerline networks. First, the HomePlug technology and its medium access function is introduced. Then the CSMA/CA algorithm parameters of HomePlug are analyzed. The results show that the parameters of this algorithm should be skipped for analytical modelling. Therefore the one parameter analytical model has been created and is introduced. The results from this model are compared with simulations of HomePlug at the end of this work.*

Streszczenie. *Przedstawiono technologie HomePlug przesyła danych przez sieć elektryczną oraz funkcję dostępu do medium. Zaproponowano model analityczny sieci bazujący na parametrze BC. Modelowanie sprawdzono metodami symulacyjnymi.* ***(Modelowanie dostępu do medium w technologii HomePlug)***

Keywords: HomePlug, TDMA, CSMA/CA, backoff algorithm modelling, markov chains.
Słowa kluczowe: HomePlug, PLC, przesyłanie informacji.

Introduction

The Internet and other modern networks is a phenomena of these days. The network infrastructure and telecommunications networks are among the most widely used to access networks to other data connections. The powerline communication (PLC) is one of communications used for broadband and narrowband data transfer. We must consider PLC technology as potential channel, because the technology takes the advantage of no additional wiring required. Nowadays used modulations are very resistance against interferences. The limited transfer rate is sufficient for using PLC for smart metering, smart grid and remote data acquisition or a small home networking (see Fig. 1). PLC systems

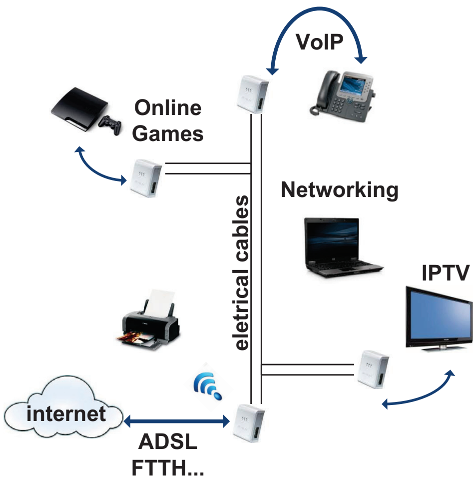

Fig. 1. An example of the powerline technology using in the homes.

can be divided into two areas: broadband PLC and narrowband PLC. Broadband PLC achieves the characteristics of broadband communication, enabling, for example, fast Internet access or implementation of small LAN networks. The broadband technology works in frequency range 150 kHz to 34 MHz and its theoretical maximum speed is 200 Mbit/s [1, 2].

Narrowband PLC is used mainly for specific services including central management of power consumption, tariffing, remote meter reading, controlling, etc. The narrowband technology works up to a maximum frequency of 150 kHz and its theoretical bit rate is of the order of kilobits up to 2 Mbit/s [1].

The theoretical speed is often calculated from variables of physical layer or it is measured under ideal conditions. The power cables were not originally designed for this technology and therefore its behavior is depended on a network status, network topology, length of wires, the equipments used in the network etc. The transmission rate rapidly decreases with increasing distance between source and destination as it can be seen from Fig. 2 showing our measurements of broadband PLC technology.

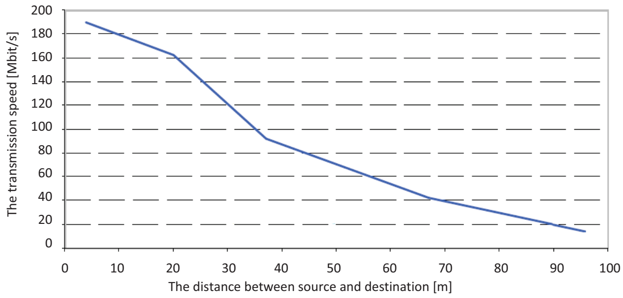

Fig. 2. The measuring of the broadband powerline technology (HomePlug AV) in a home enviroment.

This paper is focused on MAC layer but we work on physical layer as well [3, 4]. Although the PLC technology is wired technology, the CSMA/CA is most widely used instead of the CSMA/CD in PLC technology [1]. It is due to the environment in which technology is used. We are focused on a contention period analyzing in this paper.

For the purpose of modelling, PLC communication access system can be set up using Markov chain as it has been firstly presented by Bianchi [5]. There is a two dimensional Markov chain used for a modelling of a medium access control. The basic parameters of CSMA/CA of IEEE 802.11b [6] are used as a main parameters of the Markov functions. The Tripathi *et al.* [7] used the two dimensional Markov chain for HomePlug 1.0 [8] modelling as well as Bianchi used it for wireless modelling. Three dimensional model was introduced by authors Jung *et al.* in [9]. It is very hard to obtain the analytics results from these Markov chains. Yoon *et al.* [10] used a numerical simulation to obtain a optimal contention window in HomePlug AV technology. The organization of this paper is as follows. The next section describes the access method used in HomePlug AV system. Then we shortly describe CSMA/CA algorithm used in HomePlug. Next, we describe the approaches of analytical models of HomePlug and we show one dimensional analytical model. The conclusion is on the end of paper.

Medium access control scheme in HomePlug AV

HomePlug uses OFDM modulation and a powerful Turbo Convolutional Code (TCC) at physical layer and hybrid model at medium access layer. The OFDM modulation is based on the simultaneous transmission of a large number of orthogo-

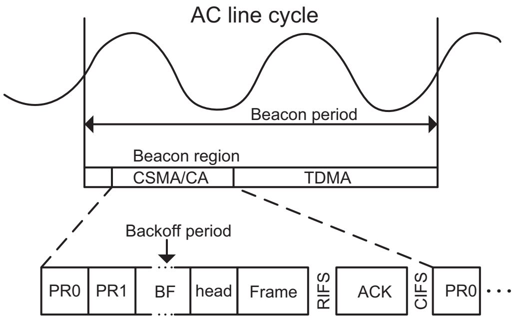

Fig. 3. A beacon period in the HomePlug AV.

nal carriers with a very narrow bandwidth. The HomePlug AV uses up to 917 usable carriers in the 2- 28 MHz range. For each carrier an appropriate modulation and coding is chosen. HomePlug brings a hybrid scheme for medium access control. A beacon message is periodically broadcasted by the coordinator in each AC line cycle. As shown in Fig. 3, it divides beacon period into Beacon Region - a time where the beacon is transmitted, a CSMA region - a time where the contention of medium is provided and a contention free region - region for exact time for access to shared medium.

The CSMA/CA is used for the access in the contention period. The same CSMA/CA method is also used in HomePlug 1.0 [8]. There are the differences in time of CIFS (Contention InterFrame Space) and RIFS (Response InterFrame Space). The TDMA is used for the second part of access scheme of HPAV. Thus some modern services can be supported in this part (VoIP, IPTV etc.). Each HPAV network has a central coordinator for providing these services.

CSMA/CA algorithm in the HomePlug technology

The CSMA/CA used in HomePlug is similar to IEEE 802.11b. There are extra the deferral counter (DC) and the priority resolution slots in HomePlug backoff algorithm. The deferral counter serves to reduce the collision in the network. The priority levels are chosen using two priority resolution slots (PRSs). Both slots consist of two 35.84 μsec long frames. Before transmission begins, all stations having frame to transmit must define the priority level using these slots. The combination of these slots gives a specific level of frame to be transmitted. The combinations are given by Tab. 1.

Table 1. The combinations of PRSx for the priority level resolving .

Priority level	PRS0	PRS1
CA3	1	1
CA2	1	0
CA1	0	1
CA0	0	0

Once the priority level is chosen all stations start the backoff procedure based on this level. Let us suppose the priority level CA3. If the CA3 level is set, all stations having frames with same level can enter to the backoff procedure. The rest of the stations with other levels have to wait for other round for lower priorities. After the successful transmission, the next round of priority resolution can start after CIFS.

The HomePlug backoff procedure is different from IEEE 802.11b standard. The IEEE 802.11b standard uses two counters while the HomePlug standard uses several counters. Not all of counters are used for modelling. Generally, four basic values are used for modelling and simulation:

- BPC - Backoff Procedure Event Counter,
- BC - Backoff Counter,
- DC - Deferral Counter,
- CW - Contention Window.

The *BPC* and *BC* counters represent the number of retransmissions. These values correspond to the *s* and *b* values in IEEE 802.11 [7, 6]. The stations in backoff procedure set up $BPC = 0$ first. Then the *BC* value is randomly chosen from interval $BC =< 0, CW_0 >$. According to BPC value, *DC* is initialized as in Tab. 2 respectively. After this, the BPC is immediately increases by one.

Table 2. The backoff procedure values of HomePlug system.

BPC	Priorities CA3, CA2		Priorities CA1, CA0	
0	DC = 0	CW(W_0) = 8	DC = 0	CW(W_0) = 8
1	DC = 1	CW(W_1) = 16	DC = 1	CW(W_1) = 16
2	DC = 3	CW(W_2) = 16	DC = 3	CW(W_2) = 32
3+	DC = 15	CW($W_{3...}$) = 32	DC = 15	CW($W_{3...}$) = 64

The BC and DC values are reinitialized whenever the BPC is newly set after first initialization. Thus the stations have an own random interval for medium detection. The contention window interval consists of the timeslots. Each timeslot is 35.84 μsec long. The number of timeslots equals to the BC number. If a slot is sensed idle, the BC value is decreased by one. The DC is fixed in the idle slot. If a slot is sensed busy, the BC and DC is decreased by one. The stations can send their frame when the $BC = 0$. If the station detects the collision then its BPC is increased by one. The BPC increases by one when $DC = 0$ and medium is sensed busy. The DC and BC are reinitialized when BPC is changed. To effectively support quality of services and resolve collision, different backoff values DC and BC are defined for each priority level.

Modelling of the HomePlug technology

From the previous section we can observe, that the saturation of this network (from BC view) is around 15 nodes. Therefore we can say that the three dimensional level of Markov chain introduced by Jung *et al.* [9] can be seen as unnecessarily complicated. We assume some notes before the simulation model creating:

- there are *n* stations in system,
- each station has infinity memory for their frames,
- after frame transmission there is new one for new transmitting,
- all stations have frames with same priority,
- collisions are detected immediately when there are at least two stations with $BC = 0$.

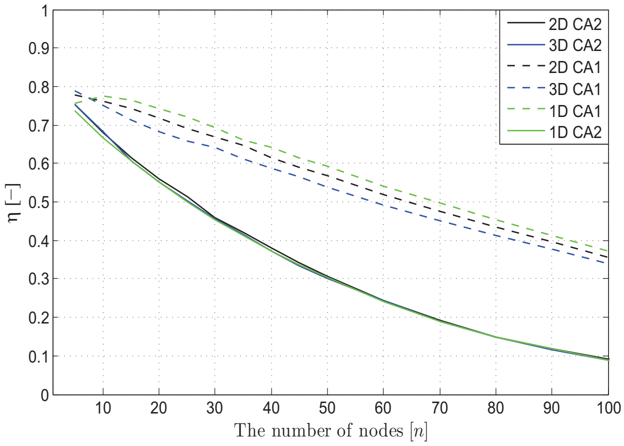

Fig. 4. The simulation of the approches for HomePlug modelling.

As mentioned above, the Tripathi *et al.* [7] used the two dimensional Markov chain for HomePlug modelling. They used BC and DC parameters in two dimensional chain. Three dimensional model was introduced by authors Jung *et al.* in [9]. They used all backoff parameters for HomePlug modelling.

Our simulation of HomePlug suggests that these parameters are not important for MAC throughput as shown in Fig. 4. This idea has helped us to realize a freer model with one parameter - one dimensional model of CSMA/CA.

All approaches got a steady state results after the sufficient number of iteration. All results are more or less equivalent. The differences between results of stricter priority mode are lesser than results of the second priority. We can say, that the parameters DC and BPC should be skipped for one dimension model realization. A recursive calculation of probabilities for each transmission round was chosen to determine the model.

One dimensional model of HomePlug

The Fig. 5 introduces our basic chain of proposed model. There are n nodes in given network and representation in Fig. 5 is one of them. The BC parameter is used for our one dimensional model.

An idle, a transmission, and a collision are the events we distinguish. The probability of successful transmission if given by a p_s. The collision in the system is given by a probability of collision p_c. The probability that node will be in idle mode when its $BC > 0$ is one.

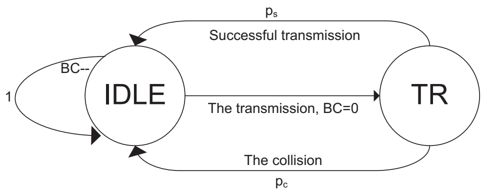

Fig. 5. One dimensional Markov chain for HomePlug system.

Let us suppose two nodes i in a network. If there exists only one parameter for a random values generation to provide a random access to a medium, it is simple to get the probability of each time for the access, that is identical for each transmission. Two nodes are in collision

$$p = \frac{BC_{max}}{BC_{max}^n}, \tag{1}$$

or the nodes are not in collision

$$p = \frac{\prod_{i=0}^{NS} BC_{max} - i}{BC_{max}^n}. \tag{2}$$

If we suppose more than two nodes in the network, the situation with the probabilities of the random access is more complicated. It must be calculated the each probability of the each combinations that may occur [11].

As an example, let us suppose five nodes in a given network. The probability that the random values of the nodes's BC parameter will be identical is given by

$$p_1 = \frac{BC_{max}}{BC_{max}^n}, \tag{3}$$

the probability that there will be four nodes with same and one node with different BC parameter is given by

$$p_2 = \binom{n}{NS} \cdot \frac{BC_{max} \cdot BC_{max-1}}{BC_{max}^n}, \tag{4}$$

the probability that there will be three nodes with same and two nodes with different BC parameter is given by

$$p_3 = \binom{n}{NC_1} \cdot \frac{\prod_{i=0}^{NS} BC_{max} - i}{BC_{max}^n}, \tag{5}$$

the probability that there will be three nodes with one same and two nodes with different same values of BC parameter is given by

$$p_4 = \binom{n}{NC_1} \cdot \frac{BC_{max} \cdot BC_{max-1}}{BC_{max}^n}, \tag{6}$$

the probability that there will be two nodes with same and three nodes with different BC parameter is given by

$$p_5 = \binom{n}{NC_1} \cdot \frac{\prod_{i=0}^{n=NS} BC_{max} - i}{BC_{max}^n}, \tag{7}$$

the probability that there will be two nodes with one same and two nodes with different same and one node with different values of BC parameter is given by

$$p_6 = \frac{1}{2}\binom{n}{NC_2}\binom{n - NC_1}{NC} \cdot \frac{\prod_{i=0}^{NC_1+NC_2} BC_{max} - i}{BC_{max}^n}, \tag{8}$$

the probability that there will be five with different values of BC parameter is given by

$$p_7 = \frac{\prod_{i=0}^{NS} BC_{max} - i}{BC_{max}^n}, \tag{9}$$

where BC_{max} is maximum of BC value, n is the number of nodes, NS is the number of nodes with different BC and NC_x denotes the nodes with identical BC parameter and

$$\sum_{i=1}^{n} p_i = 1. \tag{10}$$

It is possible to calculate the probability of each combination in the system base on these equations. The same way can be used for deriving of all combination for larger group of nodes. The node's collision is possible to obtain from these equations as well as idle nodes.

Although as we can see, the calculation of each combinations probability for more nodes is very time consuming. Therefore a simulation script has been written. For each group of nodes the number of nodes's colliding is possible to obtain. The Fig. 6 shows the results for group of nodes from five to hounder. The collisions of more that six nodes are omitted. These probabilities are very small and they are not significant for the calculations of throughput.

The probability of successful transmission p_s is the probability where there is a node with unique BC value in the system in the actual transmission round. This probability is given by number 1 on x scale of Fig. 6.

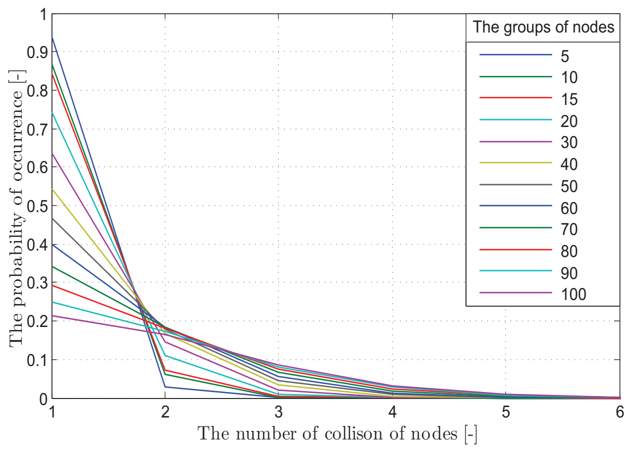

Fig. 6. The probability of node's collision occurrence of combination for CA1 priority.

(11) $$p_s = p_k,$$

where the k is number of equations. The probability of collision p_c is given by the rest of results of this simulation

(12) $$p_c = \sum_{k=0}^{n-1} p_k.$$

Thus it is easily possible to obtain the probability of idle state p_i. It is given by

(13) $$p_i = 1 - p_c - p_s.$$

Based on these results, the throughput of MAC algorithm should be calculated similar way as it was firstly introduced by Bianchi in [5]

(14) $$\eta = \frac{p_s * T_{FRA}}{p_s * T_S + p_s * T_C + p_i * T_I},$$

where p_s is the probability of successful frame transmission, T_{FRA} is the time necessary for transmission of one frame. It is given as a maximum of physical speed of used technology and maximum of frame on MAC layer. T_S is the time necessary for successful frame transmission. p_c is the probability of collision in given system. T_C is the time for collision frame. p_i is the probability that the system will be in idle mode and T_I is duration of one time slot.

The results from analytic model are in the Fig. 7. The dashed line shows the real throughput for HomePlug CA1 in saturated network. The star markers show the analytical results of same conditions. The full line shows the real throughput for CA2 in saturated network. The points show the analytical results of same conditions. As we can see, the results are similar results from other models [7, 10]. The results are not perfect because of the approximation.

Conclusion

The modeling of data networks is important for a theoretical analysis of a technology. This paper introduced a HomePlug technology and its analytical modelling. One parameter analytical model is introduced in this paper. Only the BC parameter used in CSMA/CA is used as the main value of modelling.

The introduced model is simple and still giving relevant and acceptable results. In the future we want to focus on

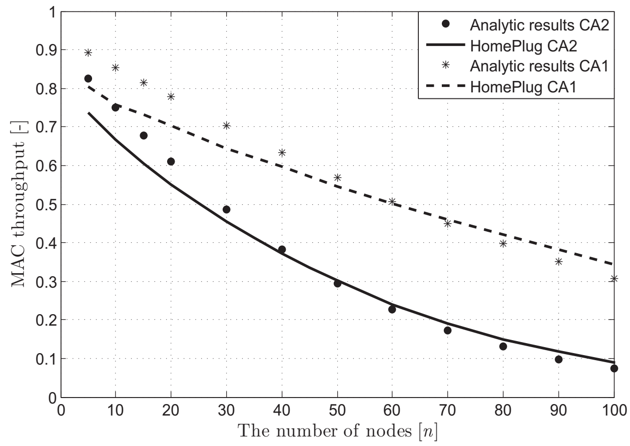

Fig. 7. The results from analytic model for HomePlug CA1 and HomePlug CA2.

optimization of backoff algorithm used in HomePlug system.

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BIBLIOGRAPHY

[1] Lehnert R. Hrasnica H., Haidine A.: *Broadband Powerline Communications Network Design*. Willey, 2004.

[2] Homeplug AV white paper, 2005. [web page] http://www.homeplug.org. [Accessed on 31 Jun. 2011.]

[3] Mlynek P., Misurec J., Koutny M., and Orgon M.: Power line cable transfer function for modelling of power line communication systems. *Journal of Electrical Engineering,*, 2:104–108, 2011.

[4] Mlynek P., Misurec J., Koutny M.: Modelling and evaluation of power line for smart grid communication. *PRZEGLĄD ELEKTROTECHNICZNY (Electrical Review)*, 8:228 – 232, 2011.

[5] Bianchi G.: Performance analysis of the ieee 802.11 distributed coordination function. *Selected Areas in Communications, IEEE Journal on*, 18(3):535 –547, March 2000.

[6] ANSI/IEEE Std. *IEEE Standard for Local and Metropolitan Area Networks - Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) Specification: High-Speed Physical Layer Extension in the 2.4 GHz Band,*. The Institute of Electrical and Electronic Engineers, New York, 1999.

[7] Tripathi K., Lee J.D., Latchman H., McNair J., and Katar S.: Contention window based parameter selection to improve powerline mac efficiency for large number of users. In *Power Line Communications and Its Applications, 2006 IEEE International Symposium on*, pages 189 –193, 2006.

[8] Homeplug 1.0 technology white paper, 2001. [web page] http://www.homeplug.org. [Accessed on 31 Aug. 2011.]

[9] Jung M.H., Chung M.Y., and Lee T.J.: Mac throughput analysis of homeplug 1.0. *Communications Letters, IEEE*, 9(2):184 – 186, 2005.

[10] Yoon S.G., Yun J, and Bank S.: Adaptive contention window mechanism for enhancing throughput in homeplug AV networks. In *Consumer Communications and Networking Conference, 2008. CCNC 2008. 5th IEEE*, pages 190 –194, Jan. 2008.

[11] Koutny M., Mlynek P., and Mrakava P.: Homeplug simulation model for analysis of the rounding functions. In *34th International Conference on Telecommunications and Signal Processing*, page 4, 2011.

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