THE USE OF PUNCTURED CONVOLUTIONAL CODES IN ORDER TO IMPROVE THE DATA SPEED RATE IN A PLC NETWORK

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ABSTRACT
POWER LINE COMMUNICATIONS (PLC) HAVE BEEN IN THE FOCUS OF RESEARCHES AND POWER INDUSTRY COMPANIES FOR THE LAST FEW YEARS. THE SOLUTIONS NEEDED TO BE IMPLEMENTED USING THIS TECHNOLOGY ARE FOR AUTOMATIC METER READING SYSTEMS. IN THIS PAPER A STUDY OF THE EVOLUTION OF PLC IS MADE AND RESULTS OBTAINED AFTER A MODEL HAS BEEN SIMULATED ON A PLC TRANSMISSION WHEN PUNCTURED CONVOLUTIONAL CODES HAVE BEEN USED. AN ANALYZE OF THE DATA SPEED TRANSFER AND ERROR RATE WAS MADE WHEN MENTIONED CODES WERE USED. IN CONCLUSIONS ARE PRESENTED ASPECTS ON THE RELEVANCE OF THE RESULTS OBTAINED AND A POSSIBLE FUTURE SOLUTION TO BE USED.
KEYWORDS: CONVOLUTIONAL CODES, PLC, NARROWBAND, ERDF

1. Introduction

Power Line Communications can be described as data transfer using as environment the power lines that are used to supply power to all electronic equipments. This type of communication is known in the literature as an abbreviation of PLC, and will be used as it is and not for Programmable Logic Controller, with which it might be confused. PLC uses the power network structure, which has the next structure: from power plants through high voltage lines (100 kV - 400 kV) or very high voltage (> 400 kV) to the medium voltage (1 kV - 100 kV) to the low voltage (<1 kV) power line which supplies

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household consumers through the use of power transformers used by the power distribution network.

PLC has been designed to control equipment in substations and to make measurements by Swiss engineers since the early twentieth century. This communication technique was used in the Second World War by some radio amateurs. The first reference to this technology was made by the American Institute of Electrical Engineering (AIEE) in the publication "Guide to Application and Treatment of Channels for Power Line Carrier" [1]. Since then, research of the possibility of communication using power grid began to get the interest of many centres and companies, bringing it to experience a significant increase in solutions and performances between 1980 and 1990. So far research focused on using the PLC over the low voltage power lines, although some developers are providing equipment that can make possible the communication to take place over the medium voltage power lines too. The use of power lines raised issues from the beginning because they were not designed to allow data transfer, ensuring minimum protection in case of external electromagnetic noise and perturbations induced by the start and stop of electronic equipments. Although this was a major drawback which has been identified and taken into account from the beginning of its development, researchers have tried to find ways to make the communication possible over long distances with the increase of the speed transfer in concordance with the technology used. PLC was designed to serve two main needs: local area network or internet connection for computers and automatic power meter reading and management. For this purpose, there have been defined internationally recognized standards and separate frequency bands, the first in the frequency band 1 MHz - 30 MHz (as for broadband), and the second in the frequency band 3 kHz - 500 kHz (as for narrowband), each adapted according to country or geographic references where communication PLC is used.

In Europe and U.S. governmental entities have considered that PLC technology can be a candidate for Smart Grid applications. Therefore, has been defined a frequency band where the technology can operate in order to ensure consistency in the market. European Committee for Electrotechnical Standardization (CENELEC) published the standard EN 50065[2], that allows communication over low voltage (LV) and medium voltage (MV)

[1] www.eurox10.com/contect/x10signalTheory.htm, accessed October 5, 2012;

[2] CENELEC, Signaling on low-voltage electrical installations in the frequency range 3kHz to 148.5kHz Tech. Rep. EN 50 065-1, 1991;

power lines in the frequency range 3 kHz - 148.5 kHz in Europe. In addition, this band was divided into 4 sub-bands:

• A: 3 kHz - 95 kHz, reserved for utility applications;

• B: 95 kHz - 125 kHz, for any application;

• C: 125 kHz - 140 kHz, for home network control systems with the use of the medium access control technique CSMA/CA (Carrier Sense Multiple Access/Collision Avoidance);

• D: 140 kHz – 148,5 kHz, for alarm systems and security.

In the U.S., the Federal Communications Commission (FCC) defines the frequency band of 10 kHz - 490 kHz for general supervision of public power system[3].

PLC technologies implemented to date[4]:

• G1 - S-FSK (Spread Frequency Shift Keying) - IEC 61334

• PRIME (Powerline Intelligent Metering Evolution) – OFDM (Orthogonal frequency-division multiplexing), by PRIME Alliance

• G3-PLC - OFDM, by ERDF (Électricité Réseau Distribution France)

• 4GPLC ™ – OFDM, by EnVerv

2. Convolutional codes

Convolutional codes are codes involved in the control and error correction. The encoding process for convolutional codes is carried out continuously, so a number of data with rate R_i is transformed through coding to a series of data with the rate $R_o > R_i$. Convolutional coding is stronger than the block coding it allows to obtain higher coding gain at the same complexity.

Convolutional codes are generated by a shift register with n cells and k sum bocks performing sequence correspondence between input and output as shown in Figure 1. The code is defined by the following parameters:

• k is the number of data bits entering the encoder at a time;

[3] Federal Communications Commission, Inquiry Regarding Carrier Current Systems, including Broadband over Power Line Systems, ITU-T, Tech. Rep. FCC 03-100, 2003;

[4] http://www.enverv.com/standards.php, accessed August 7, 2012;

• n is the number of bits output resulting from the encoder after processing the k data bits;

• connections between cells shift register are of modulo 2 sum blocks;

• based on the above parameters can be obtain a code that has the rate R = k / n.

A key feature of convolutional encoder is that this type of encoder has memory, meaning that each output symbol depends on the current input bit and the other (k-1) bits of the previous entry[56].

Punctured convolutional codes – the puncturing idea is to remove some bits of the coding sequence according to fixed rules. Overall scoring a code rate k / n is defined using the n vectors pointing. Each table contains p bits, where p is the period of scoring. If the bit is 1, then the corresponding code bit is not removed if the bit is 0 the corresponding bit is deleted. Punctured vectors of N make the matrix P of size N x p.

Standard matrices[7] for ½ convolutional code rate can be seen in Table 1:

Table 1 - Classic rates of convolutional codes

Code rate	Puncturing matrix
2/3	$P = \begin{pmatrix} 1 & 0 \\ 1 & 1 \end{pmatrix}$
¾	$P = \begin{pmatrix} 1 & 0 & 1 \\ 1 & 1 & 0 \end{pmatrix}$
5/6	$P = \begin{pmatrix} 1 & 0 & 1 & 0 & 1 \\ 1 & 1 & 0 & 1 & 0 \end{pmatrix}$
7/8	$P = \begin{pmatrix} 1 & 0 & 0 & 0 & 1 & 0 & 1 \\ 1 & 1 & 1 & 1 & 0 & 1 & 0 \end{pmatrix}$

Without puncturing sequence scoring a vector of bits u = (0,0,1,1,0) generates the non punctured code U_{np} = (00,00,11,01,01). Using the scoring matrix P = (1 1 1 0/1 0 0 1) and period scoring 4, only 3 of the 4 bits of the original code are used, others are deleted. Punctured code rate becomes R = 4/5 and u is encoded in u_p = (00,0,1,1,01). This code can

[5] G. M.Panaitescu, Transmiterea si codarea informatiei, Note de curs, Ploiesti, 2011;

[6] M. Cluzeu, M. Finiasz, Reconstruction of Punctured convolutional codes, IEEE Information Theory Workshop, Taormina, Sicily, 2009, 75-79;

[7] http://www.1-core.com/library/comm/viterbi/, accessed October 20, 2012;

then be decoded using various decoding schemes. The representation of a convolutional code with the rate = 2/3 can be seen in Figure 2[8].

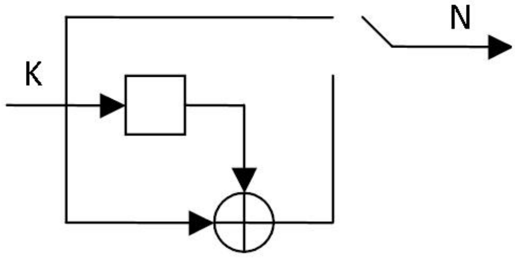

Fig. 1 – Block scheme of a convolutional code with rate of 1/2

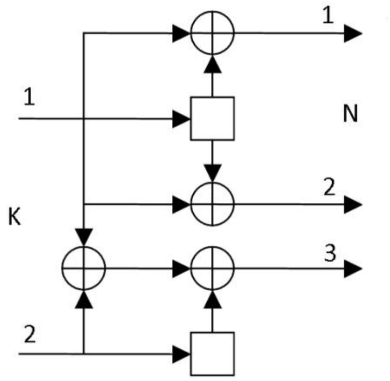

Fig. 2 – Block scheme of a convolutional code with rate of 2/3

3. Model simulation

Since convolutional codes are used in PLC equipments block structure, an analyze of the impact of communication when using punctured convolutional codes has been made. For this, a model has been developed in which a transfer of data through a structure close to that of a PLC transceiver has been realized. An analyze of the number of bits lost (BER) when communication was through an environment with enhanced noise attenuation signal was made. The model has, as can be seen in Figure 3, the following main building blocks: convolutional code, interleaver, modulator DBPSK, inverse fast Fourier transform, noisy communication channel, Fast Fourier Transform, DBPSK demodulator, deinterleaver and Viterbi decoding algorithm. The simulations took into account changing parameters of the convolutional encoding blocks for transferring the same number of bits when the code rate took values of ½, 2/3, ¾ and 5/6 with the use of puncturing.

[8] Victor Tomashevich, Pavol Hanus, Convolutional Codes, http://wwwmayr.informatik.tu-muenchen.de/konferenzen/Jass05/courses/4/papers/Victor_Tomashevich.pdf, accessed September 10, 2012;

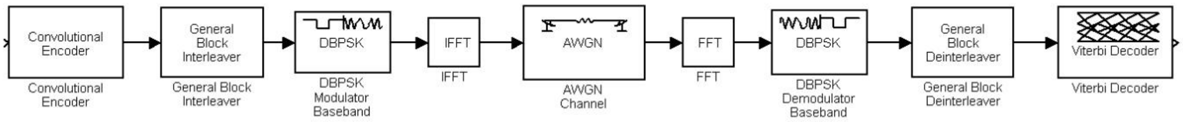

Fig. 3 –Transceiver block scheme

Obtained result after simulation of bit data transfer when convolution rate was different but the same amount of bits have been transferred can be observed in Table 2 in terms of BER.

Table 2 – Convolution rate vs. BER

Convolution rate	Lost bits	Total bits sent	BER
1/2	2357	8008	0,29433
2/3	2610	8008	0,32592
3/4	2125	8004	0,26549
5/6	2063	8010	0,25755

In order to make a more precise analysis we have analyzed the total number of bits transmitted and the bit lost, comparing the BER values for the cases previous presented. Thus, it can be seen that the standard rate ½ of convolutional codes is not much exceeded in BER value, the best value obtained was at the convolutional code rate of 5/6.

4. Speed rate transfer math

Power Line Communications can reach transfer speeds up to 1 Mbps. A theoretical calculation of the transfer data rate can be achieved as specified in[9] with the following equation:

$$T_{frame}=\frac{(((N_S+N_{FCH})*(N_{CP}+N-N_0)+(N_{PRE}*N)))}{F_S} \quad (1)$$

where:

N_s - number of symbols per frame = 40

[9] Electricite Reseau Distribution France, PLC G3 Physical Layer Specification, Project PLC G3 OFDM, 2009;

N_{FCH} - number of symbols FCH = 13

N_{CP} - prefix number of overlapping cycles = 30

CC_{rate} - convolutional code rate = ½ (standard)

N - number of FFT points = 256

N_0 - number of samples overlap = 8

N_{PRE} - number of symbols in the preamble = 9,5

F_S - sampling frequency = 400.000 Hz

PL - parity bits = 8

T_{frame} = 0.043 s

MAXRS – maximum number of symbols at the output of Reed Solomon encoder = 21

Data rate = (MAXRS - PL) * PL = 104 bits

Using the equation (1), data transfer speed of PLC when a convolutional code rate takes several values. In figure 4, is presented a comparative analysis when convolutional code rate takes values between 1/5 and 1 in case of Reed Solomon code robustness is 1/4.

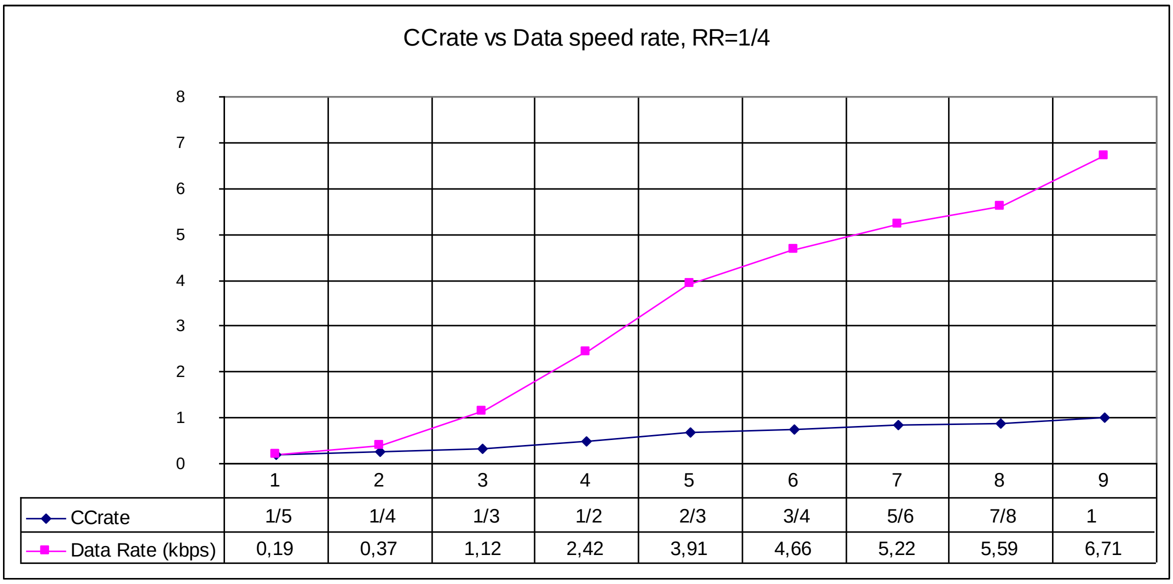

Fig. 4 – Transfer data rate variation related to the convolutional rate when robustness is 4

In the fig. 4 it can be noticed that the transfer data rate increases with the increasing convolutional ratio, the maximum is reached when the CCrate takes the value 1. This is almost 3 times higher than in the standard case when CCrate takes the value ½, that is 6,71 kbps versus 2,42 kbps. If a lower ratio than ½ is considered that the transfer rate drops significantly, to several bits per second reaching 0,1 kbps.

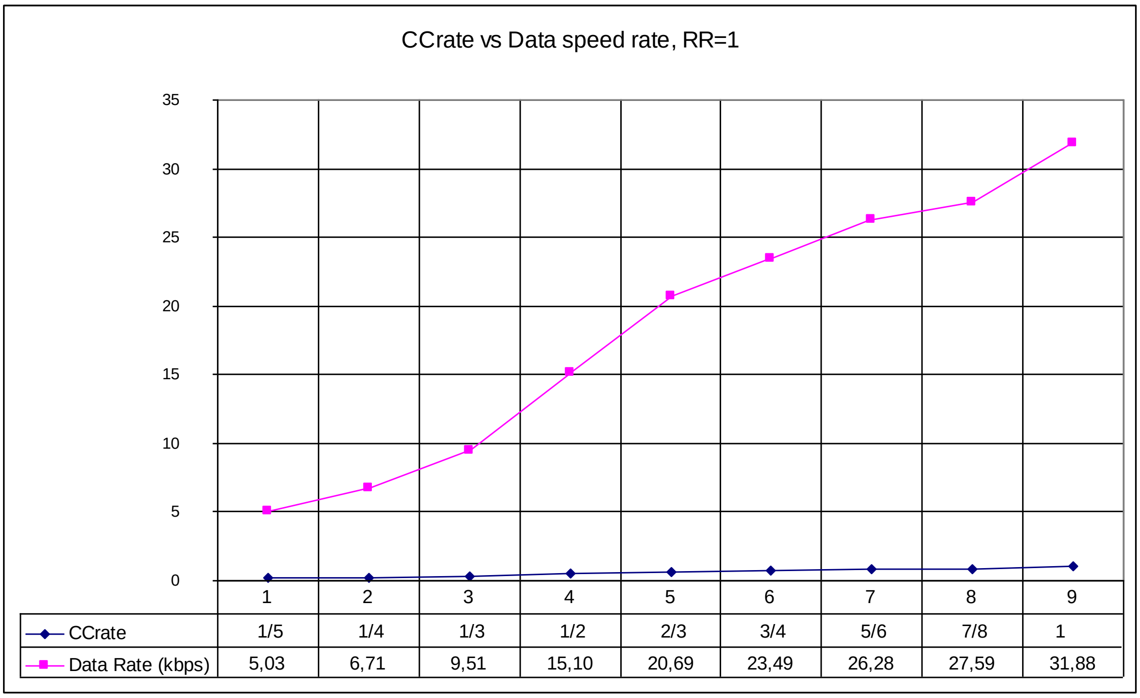

Fig. 5 – Transfer data rate variation related to the convolutional rate when robustness is 1

The mathematical approach was repeated in case of Reed Solomon code robustness taking the value 1. Data obtained can be viewed in Figure 5.

In Figure 5, we can see an increase transfer data rate when Reed Solomon code robustness is 1, which was to be expected in comparison with the previous case. Using a convolution ratio as close to the value 1 results in a significant increase transfer speed up to 2 times the standard case, ½ of 15,1 kbps to 1 of 31.8 kbps.

5. Conclusions

Convolutional codes are used in most communication systems. Their integration in communication using the power grid can result in a significant increase, in transfer data rate and decrease the number of errors. Using the punctured convolutional codes may lower the number of bit errors when communication is performed through noisy environments and increase transfer speed. This can be seen from the simulated model and the mathematical approach from where it can be observed that the higher percentage value of convolutional rate without reaching a value of 1 improves communications. Using punctured convolutional codes brings an additional advantage when communication takes place through noisy environments.

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Content

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