Comparison of PLC G3 and PRIME

Martin Hoch
Institute for Information Transmission, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany
hoch@LNT.de

***Abstract*—For the emerging IEEE 1901.2 standard on Narrow–Band Power Line Communications there are two proposals regarding the Physical and Medium Access Control Layer—PLC G3 and PRIME. In this paper, the Physical Layers of both drafts are compared to each other, by theoretical analysis as well as simulation results.**

I. INTRODUCTION

Power Line Communications (PLC) have not been standardized for a long time, but only some regulations have been established like CENELEC norm EN 50065-1. In addition to the standardization efforts on Broad–Band PLC for in–home PLC–based Local Area Networks and internet access (IEEE P1901.1 [1]), standardization of Narrow–Band PLC for SmartGrid applications has been started, too.

The committee has to discuss two proposals regarding the Physical and Medium Access Control Layer: PLC G3, which has been launched by ERDF and Maxim, and PRIME, initialized by the PRIME Alliance (Iberdrola, Texas Instruments et. al.).

In this paper we will focus on the respective Physical Layers, only, which are specified in [2] and [3].

Both drafts intend to use CENELEC A band by Cyclic Prefix (CP) Orthogonal Frequency Division Multiplexing (OFDM) in combination with coded Differential Phase Shift Keying (DPSK), which is known to be a simple and robust technique for data transmission over frequency selective channels as OFDM can be implemented highly efficiently by the Fast Fourier Transform (FFT) and DPSK modulation allows for receivers without any channel estimation algorithms.

In the following short overviews of PLC G3 and PRIME will be given in Sections II and III, respectively. After that, Section IV discusses the differences of both proposals from a theoretical point of view while Section V presents simulation results for typical power line channels. Finally, conclusions are given in Section VI.

II. PLC G3

The PLC G3 system is operating at a sampling frequency of $f_\mathrm{s} = 400\,\mathrm{kHz}$ and uses an FFT size of $M = 256$, leading to a subcarrier spacing of $\Delta f = 1.65625\,\mathrm{kHz}$. Thus by modulating carriers No. 23 to 58, only, G3 occupies the frequency range 35.9–90.6 kHz.

Fig. 1 shows the block diagram of a PLC G3 transmitter. For data transmission G3 offers three modes “Robust”, “DBPSK”, and “DQPSK” [1], facilitating packets of data of at maximum 133, 235, and again 235 bytes, at a data rate of 33.4 kbps maximum (in DQPSK mode).

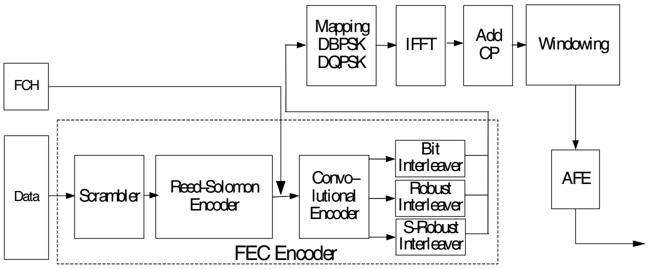

Fig. 1. Block Diagram of PLC G3 (from [2]). FCH: Frame Control Header. FEC: Forward Error Correction. DBPSK: Differential Binary Phase Shift Keying. DQPSK: Differential Quaternary Phase Shift Keying. IFFT: Inverse Fast Fourier Transform. CP: Cyclic Prefix. AFE: Analog Front End.

In all modes data are protected by the rate–1/2 convolutional code with generator polynomials 171 and 155 and interleaved within the whole packet. Frame Control Header (FCH) data and data in Robust mode are additionally repeated six and four times, respectively, by the interleaver prior to DBPSK modulation (repetition coding). Non–FCH data are encoded with an appropriately shortened Reed Solomon (RS) Code, too, which is based on RS (255, 247) for Robust, and RS (255, 239) for DBPSK and DQPSK mode.

The PSK symbols are differentially encoded per subcarrier in time (t-DPSK), thus carriers that suffer from frequency selective attenuation or disturbance can be switched off. Thereto, the subcarriers are arranged in nine groups and a “Tone Map” field in the FCH indicates which of them are active.

Furthermore, each OFDM symbol is windowed by a raised–cosine slope of 8 samples at its beginning and end for spectral forming, thus the guard interval is reduced from $L_\mathrm{CP} = 30$ samples to an effective length of 14.

The parameters of PLC G3 are summarized in Table I, 2nd column. For further details regarding PLC G3, the reader is referred to [2].

III. PRIME

In PRIME the sampling frequency has been chosen to $f_\mathrm{s} = 250\,\mathrm{kHz}$, while the FFT size is $M = 512$, i.e. the subcarrier spacing accounts for $\Delta f = 488\,\mathrm{Hz}$. As carriers 86–182 are used for transmission, the PRIME signal is located in the frequency range 42–89 kHz.

The signal processing in a PRIME sender is depicted in Fig. 2. By selecting the modulation scheme DBPSK, DQPSK, or D8PSK and switching on or off the convolutional coding

---

[1] In [4] a “D8PSK” mode is announced, too.

978-1-4244-7749-4/11/$26.00 ©2011 IEEE

TABLE I
PARAMETERS OF PLC G3 AND PRIME

	PLC G3	PRIME
frequency range	35–91 kHz	42–89 kHz
sampling frequency f_s	400 kHz	250 kHz
OFDM		
FFT size M	256	512
length of cyclic prefix L_{CP}	30	48
windowing	yes	no
subcarrier spacing Δf	1.5625 kHz	488 Hz
No. of carriers used (one–sided)	36	97
max. data rate	33.4 kbps	128.6 kbps
Forward Error Correction	Reed Solomon code, convolutional code, repetition code	convolutional code
interleaving	per data packet	per OFDM symbol
modulation differential encoding	DBPSK, DQPSK in time	DBPSK, DQPSK, D8PSK in frequency

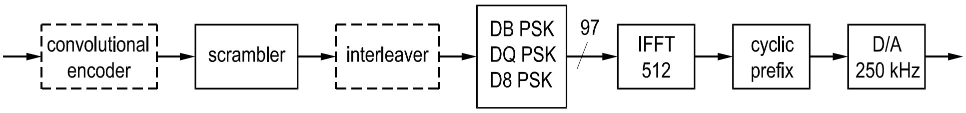

Fig. 2. Block Diagram of PRIME (according to [3]). Elements in dashed boxes are bypassed in some protocols.

(incl. interleaving), six protocols can be realized for data transmission. Thus, PRIME is able to transport at maximum 2268 bytes per packet at 128.6 kbps using uncoded D8PSK, while its most robust protocol, coded DBPSK, can carrier 377 bytes per packet at 21.4 kbps. Thereby, FCH data are always transmitted employing coded DBPSK.

The convolutional code applied in PRIME is the same as in PLC G3, however, interleaving is done per OFDM symbol. Additionally, the differential encoding of PSK symbols is performed per OFDM symbol across the subcarriers (f-DPSK).

The 3rd column of Table I provides an overview of PRIME's parameters. More detailed information regarding PRIME can be found in [3].

IV. THEORETICAL COMPARISON

Though the principle concepts are very similar in PRIME and PLC G3, both proposal differ from each other when going into details.

A. OFDM and PSD

Examining in Table I the rows relating to OFDM, one notices that PRIME uses 97 narrowly spaced subcarriers, whereas PLC G3 involves 36 widely spaced carriers for data transmission. This respective choice will be motivated in subsection IV-B, however, we comment its influence on the power spectral density (PSD) first.

Narrow subcarrier spacing favors a compact PSD in PRIME, while PLC G3 has to apply windowing to the OFDM symbol for improvement. At the end, the PSDs presented in Fig. 3 and 4 show similar envelops within 0–110 kHz.

Another interesting point is the (effective) length of the guard interval, which should be chosen subject to the channel

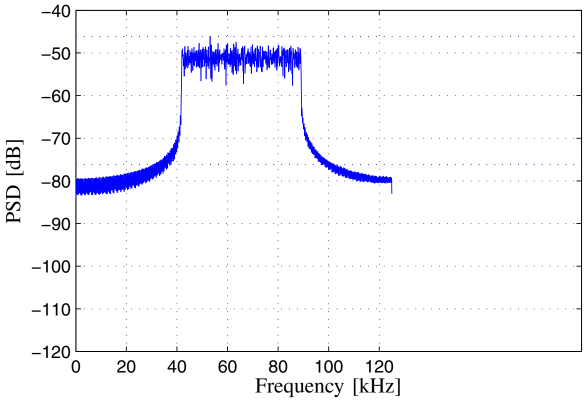

Fig. 3. Power Spectral Density of PRIME's Transmit Signal, estimated by Welch's method prior to D/A conversion.

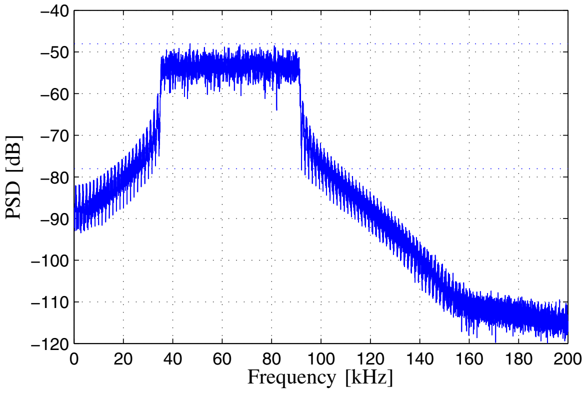

Fig. 4. Power Spectral Density of G3's Transmit Signal, estimated by Welch's method prior to D/A conversion.

impulse response. As it is 0.192 ms in PRIME, but 0.035 ms in PLC G3—i. e. the values differ by a factor of 5.5, both specification are obviously based on very unlike assumptions regarding the power line channel.

B. DPSK Modulation

The impact of the varying differential encoding direction, f-DPSK (PRIME) and t-DPSK (PLC G3) has to be considered, too. DPSK requires a reference symbol to be sent i) in every first subcarrier of each OFDM symbol in f-DPSK or ii) at the beginning of every data packet in each subcarrier in t-DPSK.

Thus, in order to reduce the overhead, f-DPSK should be used with many subcarriers, but few OFDM symbols, while the opposite holds for t-DPSK—both PRIME and G3 stick to this rule.

However, the reference symbols of t-DPSK can be chosen to form an OFDM symbol that is suited to be applied as a preamble, like in PLC G3. Additionally, this DPSK method offers the possibility of implementing notches in the spectrum in a simpler fashion, as an additional reference symbol has to be added after a notch in f-DPSK systems.

On the other hand, short-time disturbers, a typical impairment of PLC, will do a doubled harm to t-DPSK: Disturbing one OFDM symbol not only corrupts data carried by this symbol, but also impairs data detection of the following symbol as this relies on its precursor as a phase reference.

One advantage of the combination of OFDM and DPSK is the robustness against a moderate sampling frequency offset $\epsilon \overset{\text{def}}{=} \frac{f_\text{s}' - f_\text{s}}{f_\text{s}}$, which causes (besides other effects neglected here) a phase rotation in every subcarrier by

$$\Delta\phi(\mu, n) = 2\pi\epsilon \tfrac{M+L_\text{CP}}{M} \mu n, \tag{1}$$

where μ is the subcarrier index and n the counter of OFDM symbols. This would impair coherent PSK detection severely. For DPSK, after differential demodulation (i. e. calculation of phase differences between adjacent subcarriers/symbols), the resulting phase rotation calculates to

$$\Delta\phi_{f\text{-DPSK}}(n) = 2\pi\epsilon \tfrac{M+L_\text{CP}}{M} n, \tag{2}$$

for f-DPSK, which is constant for all subcarriers, but increases with time (the number of symbols n).

In contrast t-DPSK demodulation effects

$$\Delta\phi_{t\text{-DPSK}}(\mu) = 2\pi\epsilon \tfrac{M+L_\text{CP}}{M} \mu, \tag{3}$$

which remains constant over time, but grows with the subcarrier index μ.

Inserting the greatest values for n and μ according to the PRIME and PLC G3 specifications in (2) and (3), respectively, the maximum phase rotations read

$$\Delta\phi_\text{max.} = \begin{cases} 2\pi\epsilon \cdot 68.9 & \text{for PRIME,} \\ 2\pi\epsilon \cdot 64.8 & \text{for PLC G3.} \end{cases} \tag{4}$$

Consequently, both systems are likewise susceptible to sampling frequency errors.

C. Forward Error Correction

When focusing on the Forward Error Correction in PLC G3 and PRIME, we detect a big difference immediately. They both include the same convolutional code, however, PRIME allows for it to be switch off in some protocols, whereas Reed-Solomon coding is active additionally in all PLC G3 modes.

Uncoded transmission would enable high data rates under ideal conditions, however the power line channel's frequency response normally shows deep fades, which will harm uncoded transmission significantly. Therefore the question arises whether it is reasonable to specify transmission protocols without coding.

Another point to be considered is the way of interleaving. In PLC G3, the interleaver permutes data within the whole packet, so that its instruction always has to be calculated according to the requested amount of data. However, this type of interleaving can mitigate the short-time disturbers, which otherwise would have serious effects to the t-DPSK system (cf. subsection IV-B).

In contrary, interleaving is performed per OFDM symbol in PRIME, only, taking the advantage of a fixed interleaver table.

D. Preamble

At last the respective preambles shall be discussed that precede every data packet to allow for receiver synchronization. For this purpose, PRIME applies a chirp sequence over the occupied frequency range whose duration is equal to an OFDM symbol without guard interval.

Contrarily, the PLC G3 preamble consists of an OFDM symbol, which is repeated 9 and a half times whereby the last complete and the half repetition are sent with opposite sign. Thus, the probability that a receiver doesn't recognize a packet is reduced, and the symbols can be used for a very reliable per-subcarrier SNR estimation in the spectral domain.

In terms of literature [5] both preambles are non-ideal as they are relatively long and do not show the CAZAC property, so both proposals could be improved with respect to this point.

V. EVALUATION BY SIMULATIONS

In order to evaluate the performance of PRIME and PLC G3, both systems have been implemented in MATLAB. As there are only little or no specifications regarding the receivers in [2] and [3], we tried to find fair comparable solutions, which include synchronization according to [5], per-subcarrier SNR estimation and soft-input Viterbi decoding.

For the sake of shortness we will refer to the individual transmission protocols/modes as PROT $\{0,1,2,4,5,6\}$ and MOD $\{0,1,2\}$ as defined in Table II. Please note that (PRIME) PROT 4 and (G3) MOD 1 both apply coded DBPSK, while (PRIME) PROT 5 and (G3) MOD 2 use coded DQPSK, so we have two pairs on which a comparison can focus in particular.

All simulations have been performed with a packet size of 133 bytes as this amount of data can be handled by any PRIME protocol and G3 mode as well. The respective frame durations

TABLE II
OVERVIEW ON PRIME PROTOCOLS AND PLC G3 MODES

	PLC G3		PRIME	
	w/o RepC	with RepC	w/o CC	with CC
DBPSK	MOD 1	MOD 0	PROT 0	PROT 4
DQPSK	MOD 2	–	PROT 1	PROT 5
D8PSK	–	–	PROT 2	PROT 6

CC: Convolutional Code. RepC: Repetition Code

TABLE III
FRAME DURATION IN MS FOR 133 BYTES OF DATA

MOD 0	190.225	PROT 0	33.408	PROT 4	58.048
MOD 1	62.375	PROT 1	19.968	PROT 5	33.408
MOD 2	40.135	PROT 2	15.488	PROT 6	22.448

are listed in Table III. With assuming equal transmit power, these values are a measure for energy consumption, too.

A. *Typical Noise on Power Lines*

The systems are investigated in a noise environment that is typical for power lines. In [6] a mathematical model for a realistic scenario has been presented, where the noise is colored and its instantaneous power varies synchronously to the voltage of the power line. Additionally, this noise model includes a periodic impulsive component.

Figs. 5 and 6 present the Frame Error Rates (FER) obtained for PLC G3 and PRIME (only protocols with coding) by simulations, respectively, over the Signal-to-Noise Power Ratio (SNR), which here is defined as the quotient of the signal power and the noise power in the frequency band that is occupied by the data signal. Due to additional RS coding PLC G3 performs better than PRIME.

B. *Frequency Selective Channels*

Regrettably, there is no commonly accepted simple model for the channel transfer function for NB-PLC in literature, cf. [7]. A suggestion can be found in [8], where the grid between a distribution transformer and the meters in the various supplied houses is described by an impedance network—a principle that is reported in the context of in-building Broad–Band PLC in [9], too. Therefore we have adopted this way of modelling and generated 1000 transfer functions $H(f)$, a couple of which is plotted in Fig. 7 for illustration.

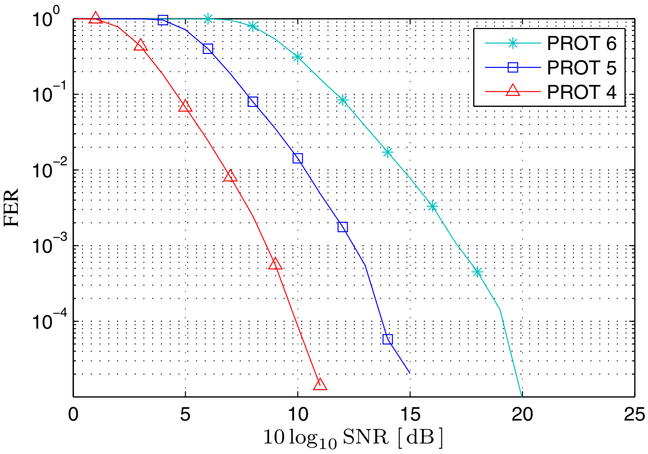

Fig. 6. Simulation Results for PRIME with Power Line Noise.

In the simulations one of that channels is chosen randomly for every transmission and AWGN is applied, too. The resulting FER graphs for PLC G3 and PRIME are displayed in Figs. 8 and 9, respectively.

Due to averaging over 1000 channel realizations the FER statistics are dominated by the "bad" channels that show a strong frequency selective behavior.

Consequently, PRIME's PROT 0–2, which operate without coding, perform poorly. As they involve additional RS coding, PLC MOD 1 and 2 outperform their PRIME counterparts PROT 4 and 5 when considering a single channel realization.

On average, however, one observes similar FERs for MOD 2 and PROT 5 at SNRs lower than 25 dB.

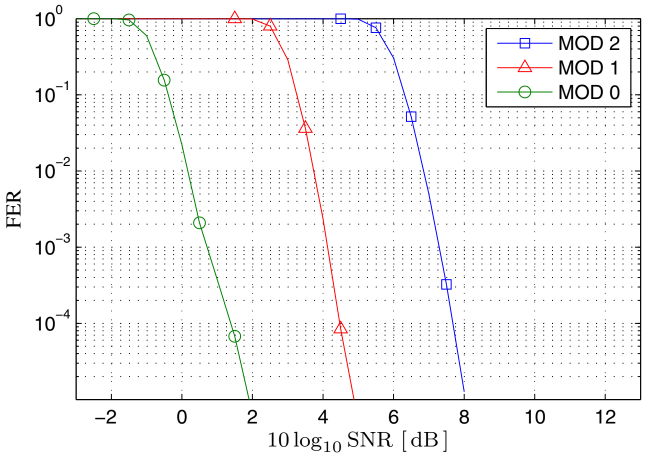

Fig. 5. Simulation Results for PLC G3 with Power Line Noise.

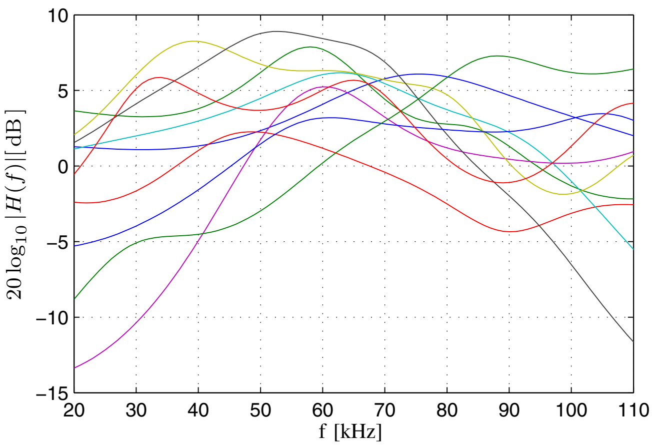

Fig. 7. Sample Channel Transfer Functions $H(f)$.

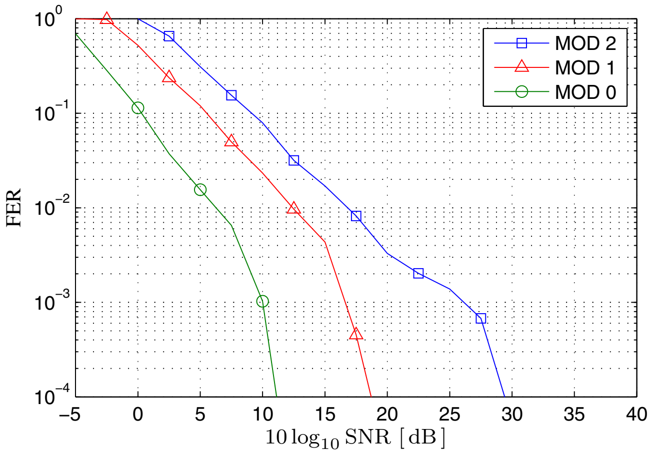

Fig. 8. Simulation Results for PLC G3 for Frequency Selective Channels. Averaged over 1000 random realizations.

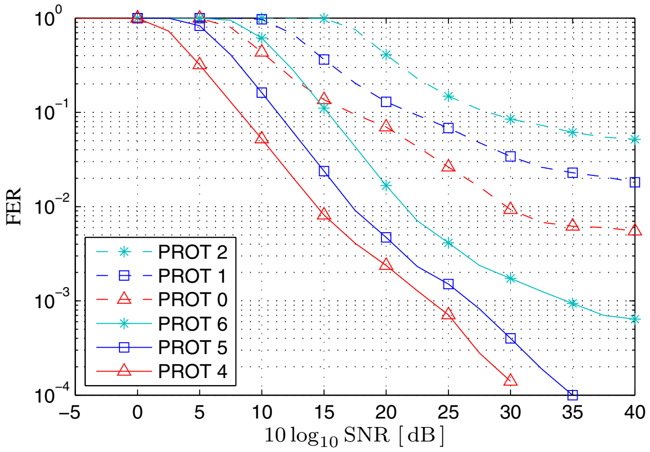

Fig. 9. Simulation Results for PRIME for Frequency Selective Channels. Averaged over 1000 random realizations.

C. *Narrow–Band Disturber*

Finally, we examine the performance of PRIME and PLC G3 in AWGN at the presence of a narrow–band disturber that is modelled by a sinusoid at 63 kHz whose power is 10 dB lower than that of the data signal. This type of disturbance is interesting especially, as PLC G3 offers the possibility to switch off communication in the affected subband by adjusting the tone map (TM).

According to the simulation results plotted in Fig. 10 this indeed improves the system's performance. With an appropriately set tone map data transmission becomes more reliable in PLC G3 MOD 2, while its counterpart PRIME PROT 5 suffers so much that communication is impossible.

VI. CONCLUSION

The Physical Layers of both PLC G3 and PRIME are based on CP-OFDM and DPSK, but we have illustrated that the distinct type of differential encoding (f-DPSK / t-DPSK) implies a great difference. By applying t-DPSK, e.g., PLC G3 allows for adaptive subcarrier allocation, which has turned out to be a reasonable feature in the simulations.

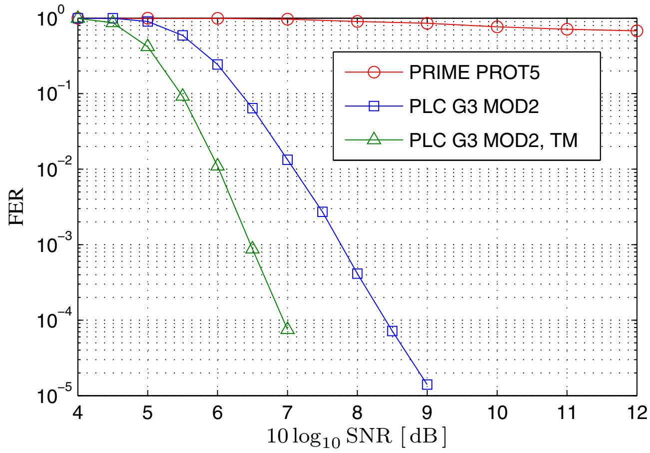

Fig. 10. Simulation Results for Scenario with Narrow–Band Disturber. TM: Tone Map is set taking into account the interferer.

Furthermore, according to both specification and simulation results, the FEC applied in PLC G3 is more powerful, while PRIME is the less complex system.

Besides, we have addressed some points where the specifications could be optimized, like their preambles. On the other hand the receivers employed in the simulations could be improved certainly, too.

Nevertheless, this paper provides a hopefully useful overview of the PRIME and PLC G3 specifications as well as insights in their performance.

REFERENCES

[1] S. Galli and O. Logvinov, "Recent Developments in the Standardization of Power Line Communications within the IEEE," *Communications Magazine, IEEE*, vol. 46, no. 7, pp. 64–71, July 2008.

[2] *PLC G3 Physical Layer Specification*, ERDF. [Online]. Available: http://www.erdfdistribution.fr/medias/Linky/PLC_G3_Physical_Layer_Specification.pdf

[3] *Draft Standard for PoweRline Intelligent Metering Evolution (PRIME)*, 1.3A ed., PRIME Alliance Technical Working Group, May 2010. [Online]. Available: http://www.prime-alliance.org/portals/0/specs/PRIME-Spec_v1 3 E_201005.pdf

[4] *Supplement to the Physical Layer for CENELEC BCD bands*, Maxim. [Online]. Available: http://www.maxim-ic.com/products/powerline/pdfs/G3-PLC-CENELEC-Supplement-B.pdf

[5] G. Bumiller and L. Lampe, "Fast Burst Synchronization for PLC Systems," in *Power Line Communications and Its Applications, 2007. ISPLC '07. IEEE International Symposium on*, March 2007, pp. 65–70.

[6] M. Katayama, T. Yamazato, and H. Okada, "A Mathematical Model of Noise in Narrowband Power Line Communication Systems," *Selected Areas in Communications, IEEE Journal on*, vol. 24, no. 7, pp. 1267–1276, July 2006.

[7] H. C. Ferreira, L. Lampe, J. Newbury, and T. G. Swart, Eds., *Power Line Communications*. Chichester: Wiley, 2010.

[8] G. Srinivasa Prasanna, A. Lakshmi, S. Sumanth, V. Simha, J. Bapat, and G. Koomullil, "Data communication over the smart grid," in *Power Line Communications and Its Applications, 2009. ISPLC 2009. IEEE International Symposium on*, March 2009, pp. 273–279.

[9] T. Esmailian, F. R. Kschischang, and P. Glenn Gulak, "In-building power lines as high-speed communication channels: channel characterization and a test channel ensemble," *International Journal of Communication Systems*, vol. 16, 2003.