Orthogonal Direct Sequence Code Division Multiple Access For Broadcast Communications on Power Lines

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ABSTRACT

This paper deals with a Direct Sequence Code Division Multiple Access (DS/CDMA) system for Power Lines Communications (PLC): it relies on utilisation of Orthogonal Variable Spreading Factor (OVSF) sequences together with scrambling codes in order to minimise Multiple Access Interference (MAI) impairments and to provide flexible multicode allocation.

Proposed scheme is particularly suitable for high bit rate broadcast communications on low voltage grid in order to guarantee "last mile" access network. System performance is expressed in terms of bit error rate (BER), which has been derived by computer simulations under the assumptions of frequency-selective multipath fading channel and additive coloured gaussian noise according to the model defined for in building networks [1].

***Keywords**: Code Division Multiple Access (CDMA), Orthogonal Variable Spreading Factor (OVSF) codes.*

I. INTRODUCTION

Data transmission and signalling over power lines has been proper solution for monitoring and control problems such as load control, various automation system, remote metering system: as it is known, this technique has been considered for a limited market because of inherent features of this communications, namely, low speed, low functionality, high cost and other barriers. Europe's energy market recent trends towards less regulation and more competition impose an increasing demand on utilities for new service besides mere delivery of energy, so creating new revenue streams.

As a consequence, growing attention has been dedicated to wired communications because of liberalisation process in telecommunications business: in particular, great attention has been devoted to low voltage grid as a way to bridge the "last-mile" access network.

Fast-Internet, voice and data services, video on demand, telephony and security are some possible examples of future Enhanced Value Services (EVS) and high data-rates are naturally involved for all these applications. As a consequence, carrier frequencies must be defined within the range from 1 MHz up to 30 MHz, suitable communication systems have to established and proper networks planning should be performed. Moreover, if the in-house power distribution grid were upgraded as a local area network in order to connect some PCs, printer, or TV-sets with VCRs, electrical appliances, digital consumer electronics, without any extra wiring, it would become a natural strong competitor to home phone line or wireless LAN.

Generally, mean data rate to be transmitted during a session may be moderate, even if peaks can seldom occur, with consequent need of additional band resources. Therefore, fixed assignment of channel capacity to all active users cannot be recommended; a flexible assignment of resources, i.e., choosing to give capacity to the active users depending on their effective requests, seems to fit better to traffic peculiarities.

As it is known, in PLC research community different channel models have been defined so that, first of all, it is worth stressing that considered propagation environment in this paper is wired communication channel inside of buildings as described in [1]. Considered communication environment main features can be identified in slow changes of channel characteristics, in the existence of many echoes i.e., multipath components, and the peculiar noise power density profile, stronger at relatively low frequency, very weak for the higher band, with the presence of extremely narrowband interference.

In PLC different multiple access techniques are taken into account in order to permit high speed communications; in particular, spread-spectrum techniques and other wide-band approaches [2,3] permit to cope with narrowband interference and noise damage at a cost of a bandwidth occupation increase.

As it is known [4], spread-spectrum signals are characterised by a bandwidth that is far greater than data rate. The processing gain (PG) denoting the ratio of the bandwidth of the transmitted signal versus the pure information bandwidth is a measure of performance. Inherent redundancy of these techniques can be exploited in order to increase system capacity by introduction of suitable multiple access schemes such Code Division Multiple Access (CDMA) [4]. Because of spectral redundancy these systems exhibit excellent robustness against all kinds of narrow-band interference, coloured noise or selective attenuation so that they are likely to be one of the most interesting candidates for communications over power lines. Unluckily, these systems are sensitive to impulse noise: during such strong peaks information bits are irremediably lost so that proper coding and interleaving schemes are needed to avoid remarkable performance loss. In this paper uncoded data flow is taken into account so that this kind of noise is not considered. Among spread-spectrum techniques, DS/CDMA seems to guarantee remarkable performance-complexity trade-off [3], together with other technical factors such as anti-multipath fading capabilities. Moreover, the greater the PG is, i.e., the greater the ratio between bandwidth occupation and the data rate, the better the effects of these attractive features are. For what concerns DS-CDMA systems hurdles, it is worth stressing that MAI limits the number of active users in relation to a specified BER.

In this paper a flexible DS/CDMA system, relying on OVSF codes utilisation, is proposed and tested in order to evaluate possibility of its utilisation in the down-stream power line channel in which high data-rates are needed and transmission is performed according to point to multipoint situation, i.e., from master control station to terminal. While in classical DS-CDMA systems each user has a distinct pseudo-noise code, in the system in exam the spreading procedure is executed in two steps: firstly, each global bit stream is divided in *n* parallel substreams, orthogonally separated each others by a channelisation operation performed by multiplying them with an individual orthogonal pseudo noise sequence, selected inside the OVSF code set; in the second step all the substreams composing the data flow of each user are added together and *scrambled* by means of a pseudonoise user code to better protect it from multipath effects and from interference of other eventual users.

This solution realises a parallel multicode communication system where different solutions are, in line of principle, possible: it is possible to divide an high date rate communication in n equal rate substreams, or considering different rates on the same time since OVSF codes permit this solution, too. All these solutions, anyway, while permitting high flexibility in resources management, are useful only if the number of users and the allocated rates not exceed the maximum bandwidth at disposal, i.e. the maximum rate occupation, because, otherwise similar MAI limits would rise. Finally, rake diversity reception can take benefit to the considered systems. The proposed scheme performance is evaluated in BER terms by means of simulations.

This paper is organised as follows: channel characteristics and system model are presented in Section II and III. Numerical results and performance comparisons are given in Section IV. Concluding comments are drawn in Section V.

II. CHANNEL CHARACTERISTICS

As it has been stated in the previous paragraph, in this paper the considered propagation environment in this paper is wired communication channel inside of buildings as described in [1]. As it is known, PL channel impedance is highly varying with frequency and, ranges between a few Ohm and a few kOhm. Furthermore, load conditions changes as well as discontinuities in branch cables can cause reflection and echoes. At some frequencies there could be peaks in the impedance characteristics. This effects lead to consider PL channel as a multipath environment propagation and to produce deep narrowband notches in the frequency response.

For what concerns power lines noise characterisation, generally speaking, noise spectrum is highly varying with frequency and time because of influences of a large number of different sources with different peculiarities; in this environment three kinds of noise can be identified: Coloured Gaussian noise, single tones, and impulse noise.

- Coloured noise is characterised by frequency dependence so that spectral power density shows a decay for higher frequency; this kind of noise has been referred as Additive Coloured Gaussian Noise (ACGN);
- single tone interference is supposed in correspondence of every narrow peak in the frequency domain;
- impulse noise are strong peaks whose worst value duration is 2.7 ms and mean time between occurrence is equal to 19 s [5].

Finally, in the model described in [1] channel characteristics are assumed not to show fast variations in time with respect to bit duration time so that channel can be considered as quasi-stationary.

Therefore, channel model assumed in this paper is based on two basic assumptions:

- each transmitted signal reaches the receiver not only on a direct path, but also through several delayed and attenuated echoes;
- proposed noise model is obtained by feeding with a white gaussian generator M linear band-pass filters and summing the outputs of this bank. For each parallel block bandwidth B_i and noise amplitude N_i have to be defined.

In order to effectively represent channel characteristics, echo model parameters set, provided in [1] and reported in Tab. 1 has been adopted; it is worth stressing that, in this multipath fading model, each replica delay, phase and attenuation are assumed known and constant during whole simulation.

Path Number	Relative Delay (μs)	Received Amplitude	Phase Offset
1	0.0	0.151	0.691
2	0.044	0.047	-0.359
3	0.095	0.029	0.591
4	0.201	0.041	2.913
5	0.326	0.033	1.012

Tab. 1. *Echo model parameters set.*

Passing to consider noise characterisation and modelling, as it has been previously stated, uncoded data flow is taken into account so that impulse noise is not considered.

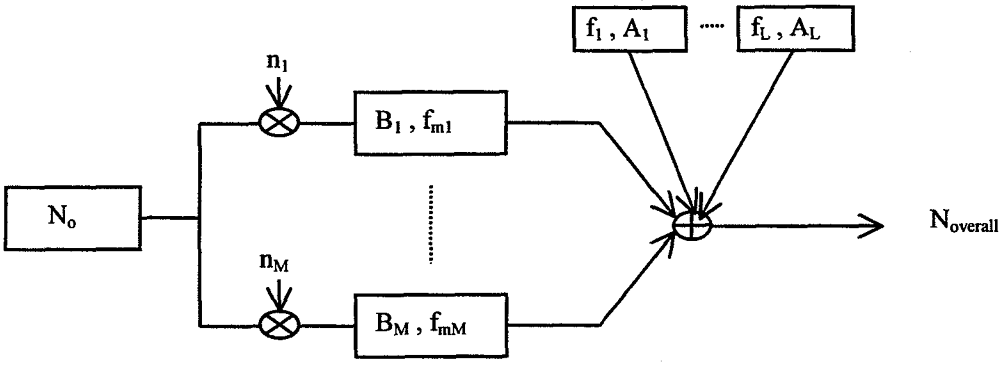

Fig. 1. *Noise model.*

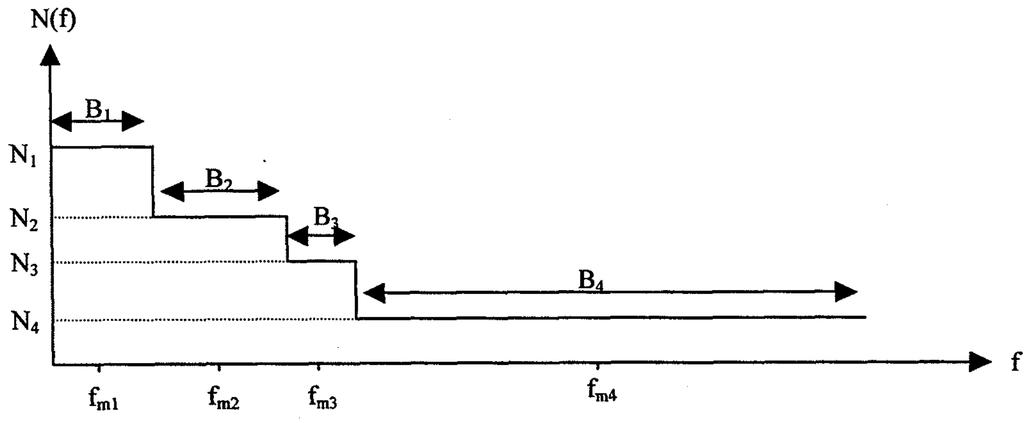

Fig. 2. *Noise shape.*

As described in Fig.1, coloured noise model is achieved by means of parallel four band pass filters, whose expressions are obtained by bandwidth B_i and noise amplitude N_i definition; linear filters outputs are added aiming to obtain power spectral density depicted in Fig.2. For each path the noise amplitude is set separately to N_i by means of a multiplication with the constant factor n_i. Moreover, after this operation four additive narrowband disturbances, each defined by frequency f_i and amplitude A_i are added. These parameters are determined in conformity to measured noise distribution exposed in [1].

Spread spectrum signals are known for their antimultipath fading capabilities: in particular, DS/CDMA systems can take benefit from the so called rake diversity techniques; signals arriving at the receiving end over different propagation paths can be resolved by a wide-band spread spectrum detector and combined by the rake receiver. Between the different combining algorithm, optimum solution is the Maximum Ratio Combiner (MRC), adopted in the proposed system.

Rake receiver general structure, described in Fig. 3, can be simplified if only *L* replicas are assumed to be resolvable: in this special case, rake receiver is composed by *L* memory cells, L correlators and a combining block.

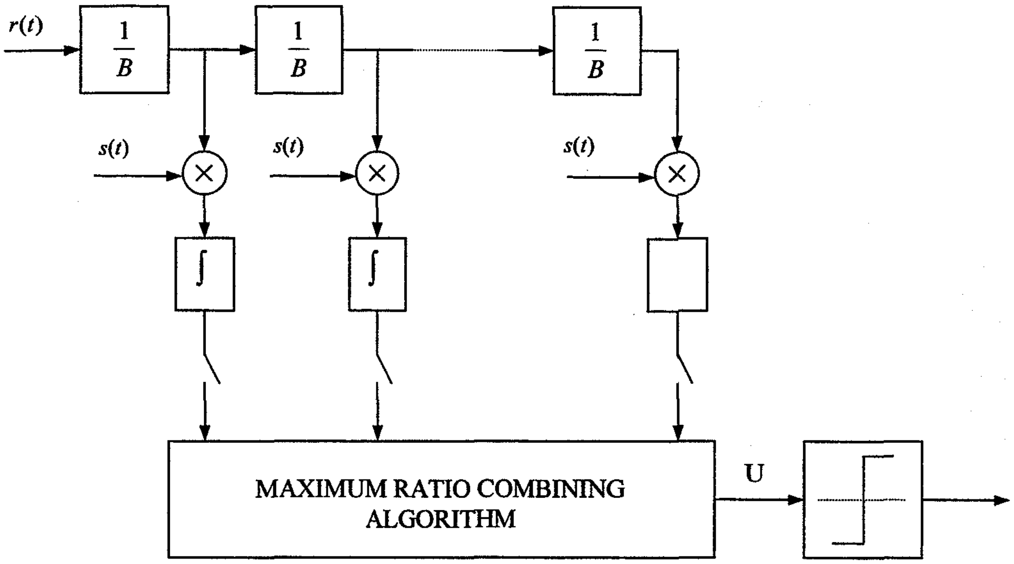

Fig. 3. *Rake receiver structure.*

III. Orthogonal DS/CDMA SYSTEM

Proposed multiple access scheme is based on joint utilisation of OVSF [6] and Gold scrambling codes: in particular, scrambling codes length is equal to 256 chips; transmitted signals are supposed to be BPSK modulated. As it is known, joint use of this two kinds of codes help obtaining fairly good crosscorrelation properties, especially if a general synchronism between users is assumed. Since proposed system is supposed to be used in the down-stream power line channel, i.e., in the communications between master control station and user locations, all the data streams can be assumed to be effectively synchronised, so completely deploying MAI impairments mitigation properties.

Anyway, straightforward introduction of spread spectrum techniques in downstream environment where high data rates are required, especially for strongly asymmetric multimedia traffic, seems not to be the best solution: in fact, for a given maximum bandwidth occupation, direct spreading operation performed on high date rate informative data stream would mean low processing gain with consequent degradation of all attractive features involved by this technique introduction.

The system proposed in this paper relies on parallel multicode CDMA concept: this means that overall informative data flow is divided into several substreams that are separately spread by means of different *channelisation* codes; after this operation, all the substreams are added together, scrambled via O-Gold codes and transmitted simultaneously on the same band. This transmitting scheme is described in Fig. 4.

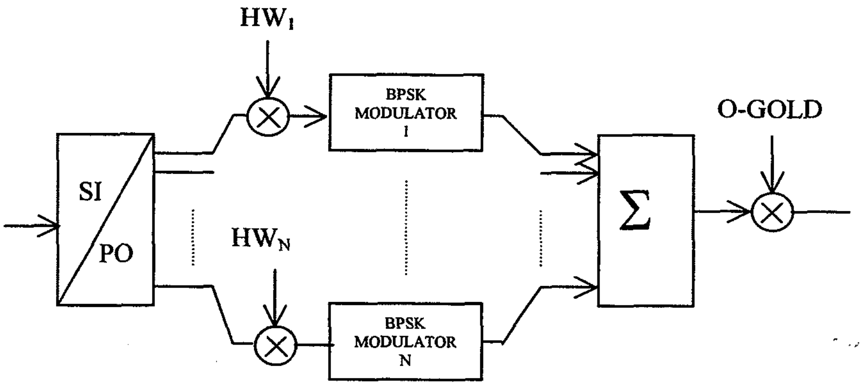

Fig. 4. *Transmitter scheme.*

It is worth stressing, that, in the proposed scheme, one individual O-Gold code per user is supposed to be used: if different informative traffic flows are supposed to be transmitted over the same link simultaneously, it would be possible to differentiate their informative streams by means of different O-Gold codes utilisation. Anyway, this solution is not considered in present work.

As it is known even from wireless communications, OVSF [6] codes permit to integrate different services and traffic at variable bit-rate with optimum and flexible resources management and to provide fine granularity in multimedia services by supporting variable data rates: in particular, these codes permit to reach same chip rate starting from substreams with different bit rate by means of Hadamard Walsh 256 codes; these sequences maintain orthogonality also among codes of different length by means of different spreading factors (from 32 up to 256). It is worth underlining that OVSF codes ideal orthogonal properties are unfortunately damaged by multipath fading phenomena.

For what concerns the receiving end, each receiver has N parallel blocks to detect all the substreams in which transmitted signal has been split, as described in Fig. 5.

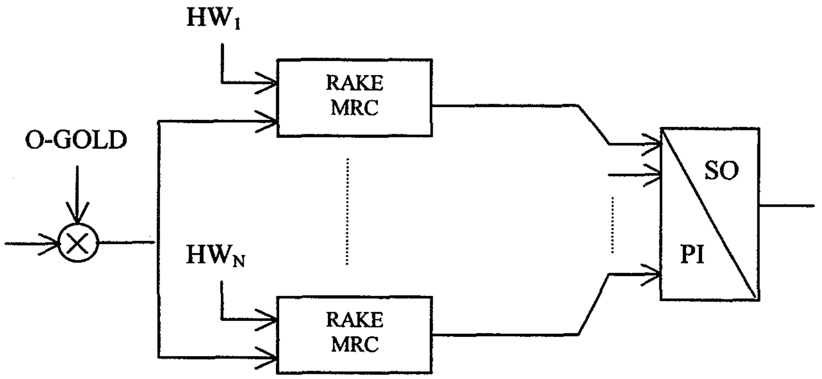

Fig. 5. *Receiver scheme.*

After descrambling operation, each substream is despread by its OVSF code. As it is clear, in the receiver there are as many rake blocks as the substreams number, and, inside each blocks as many fingers as the resolvable components of the multipath signal.

Received signal $r(t)$ can be expressed as:

$$r(t)=\sum_{n_r=1}^{N_r}\left(\sum_{k(n_r)=1}^{K(n_r)}\sum_{l=1}^{L}\sum_{i=-\infty}^{\infty}\sqrt{P^{k(n_r)}}\alpha_l\left[b_{k(n_r)}(i)\ F_{k(n_r)}(t-iT_b(n_r)-\tau_l)\right]e^{j\vartheta_l}\right)+n(t) \qquad (1)$$

where N_r is the number of different rates in the systems at the same time, $K(n_r)$ is the total number of active substreams transmitting with n_r^{th} bit rate, assuming $K = \sum_{n_r} K(n_r)$ as the total number of substreams, L is the signal replicas number, assumed constant without any generality limitation, $\sqrt{P^{k(n_r)}}$ the transmitted power of $k(n_r)^{th}$ user, $T_b(n_r)$ the bit duration of n_r bit rate sources, α_l, ϑ_l and τ_l are transmitted signal l^{th} replica attenuation, phase and delay, respectively, defined according to model [1]. Moreover, $b_{k(n_r)}(i) \in \{\pm 1\}$, with equal probability, $k(n_r)^{th}$ transmitted signal informative bit, chip and bit shapes are rectangular, $n(t)$ is the complex noise defined according to [1]. Moreover, $k(n_r)^{th}$ user spreading sequence $F_{k(n_r)}(t)$ is obtained multiplying OVSF code with O-Gold scrambling code. Parameters α_l, ϑ_l and τ_l are assumed known at the receiving end, i.e., tracked accurately. Moreover, knowledge of all the sequences is assumed. Since perfect phase recovery is assumed, output signal of the $\bar{l}^{th}$ finger $\bar{k}\left(\overline{n_r}\right)^{th}$ rake is equal to:

$$
\begin{aligned}
y_{\bar{l},\bar{k}(\overline{n_r})}(i) = {} & \sqrt{P^{\bar{k}(\overline{n_r})}T_b(\overline{n_r})}\,\alpha_{\bar{l}}^{2}\, b_{\bar{k}(\overline{n_r})}(i) + \sum_{j=i-1}^{i+1}\sum_{\substack{l=1\\ l\neq\bar{l}}}^{L}\sqrt{P^{\bar{k}(\overline{n_r})}T_b(\overline{n_r})}\,\alpha_l\alpha_{\bar{l}}\, b_{\bar{k}(\overline{n_r})}(j)\,\hat{I}_{\bar{k}(\overline{n_r}),\bar{l},\bar{k}(\overline{n_r}),l}\left((i+1)T_b(\overline{n_r})+\tau_{\bar{l}},j\right) + \sum_{\substack{k(\overline{n_r})=1\\ k(\overline{n_r})\neq\bar{k}(\overline{n_r})}}^{K(\overline{n_r})}\sum_{l=1}^{L}\sum_{j=i-1}^{i+1}\sqrt{P^{\bar{k}(\overline{n_r})}Tb(\overline{n_r})}\,\alpha_l\alpha_{\bar{l}}\, b_{k(\overline{n_r})}(j)\cdot \\
& \cdot\hat{I}_{\bar{k}(\overline{n_r}),\bar{l},k(\overline{n_r}),l}\left(\left((i+1)T_b(\overline{n_r})\right)+\tau_{\bar{l}},j\right) + \sum_{\substack{k(n_r)=1\\ n_r\neq \overline{n_r}}}^{K}\sum_{l=1}^{L}\sum_{j=i-1}^{i+1}\sqrt{P^{\bar{k}(\overline{n_r})}Tb(\overline{n_r})}\,\alpha_l\alpha_{\bar{l}}\, b_{k(\overline{n_r})}(j)\,\tilde{I}_{\bar{k}(\overline{n_r}),\bar{l},k(n_r),l}\left(\left((i+1)T_b(\overline{n_r})\right)+\tau_{\bar{l}},j\right) + \tilde{n}_{\bar{l},\bar{k}(\overline{n_r})}(i)
\end{aligned}
\tag{2}
$$

where $\hat{I}_{\bar{k}(\overline{n_r}),\bar{l},k(n_r),l}\left(\left((i+1)T_b(\overline{n_r})\right)+\tau_{\bar{l}},j\right)$ expresses the crosscorrelation between same rate substreams [7], while $\tilde{I}_{\bar{k}(\overline{n_r}),\bar{l},k(n_r),l}\left(\left((i+1)T_b(\overline{n_r})\right)+\tau_{\bar{l}},j\right)$ takes into account cross-correlation terms between different bit rates informative flows: so, it is evident that first term in (2) is due to the transmitted signal of the desired substream, the second term is the contribution of self-noise, the third term is MAI produced by same rate interfering substreams, the fourth term is MAI produced by different rate interfering substreams and the last is due to noise.

Anyway, MAI impairments are greatly reduced by system general synchronisation and, as it can be deduced from results shown in the following, proposed system based on substream splitting and OVSF codes utilisation perfectly fit to channel characteristics, taking advantage of spread spectrum techniques. Moreover, the strategy of divide data stream in same low data rate substreams results in complete elimination of interference between different rate flows while maintaining sequences crosscorrelation properties seems to be the most effective.

IV. NUMERICAL RESULTS

In this section the performance of the proposed system has been investigated in different environments conditions and for several system load configurations. In performing our simulations we have assumed the following conditions:

- PLC down-stream channel ranging from 1 MHz to 21.480 MHz;
- Considered substreams bit-rate equal to 80 kbit/s, 160 kb/s, 320 kb/s and 640 kbit/s;
- Spreading obtained through a channelisation Orthogonal Variable Spreading Factor (OVSF) code, that is a Hadamard Walsh 256 followed by a scrambling code of O-Gold 256 type; the SF is variable according to the bit rate, i.e. SF=32 for a bit rate of 640 kbit/s and SF=256 for 80 kbit/s.

The channel model is derived from [1].

In Fig 6 proposed system performance is compared for different channel noise characterisation: in particular, 16 substreams whose rate is equal to 80 kb/s are supposed to be transmitted in presence of AWGN and with the noise described in [1]. As it is clear, proposed system cope with ACGN almost ideally. It is possible to find a motivation of this behaviour in the capabilities of spread spectrum technique to eliminate narrowband interference.

In Figs. 7-9 proposed system is evaluated for different substreams configurations in presence of ACGN noise: in particular, same overall data rate is supposed to be allocated to *N* substreams whose rate is equal to *R* or to *2N* substreams whose rate is *R/2*. All the test take to the same conclusion: the strategy of dividing the whole stream in as many as possible low rate substreams is the most profitable; in fact, this choice takes to completely exploit benefits caused by great processing gain, such as narrowband interference rejection and interpath interference mitigation.

In Figs. 10-11 proposed system is evaluated for different substreams allocation policy in ACGN noise: in particular, nearly the same load conditions is obtained by splitting overall data rate in uniform rate substreams, i.e. 16 substreams whose rate is equal to 160 kb/s in Fig. 10 and 320 kb/s in Fig.11, respectively, or in a non uniform rate substreams, i.e., two substreams for each bit possible rate in Fig. 10, four substreams for each possible rate in Fig. 11. If same rate substreams are considered in the two different load conditions, it is evident that the choice of uniformly splitting overall rate take to obtain remarkably better performance. Therefore, it is possible to conclude that more flexible non uniform rate splitting has its main drawback in sensible impairments caused by interference due to different rate substreams. On the contrary, these negative effects are minimised by uniform rate choice.

V. CONCLUDING REMARKS

In this paper a DS/CDMA sytem for PLC has been presented: it relies on OVSF codes utilisation, data rate splitting and multicode substreams allocation. It has been analysed in multipath fading channel environment for downstream communications. Proposed system has been tested and investigated for different environments and load conditions; in particular suitable allocation data rates strategy has been studied and compared.

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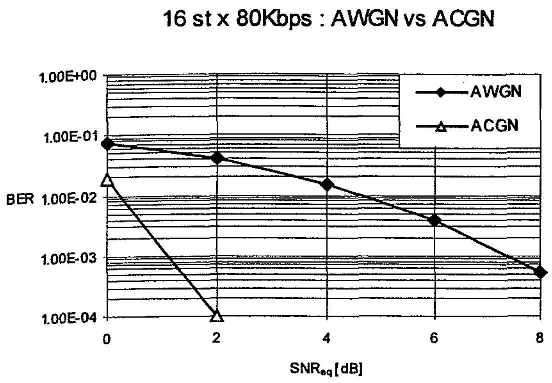

Fig. 6: *BER Performance.*

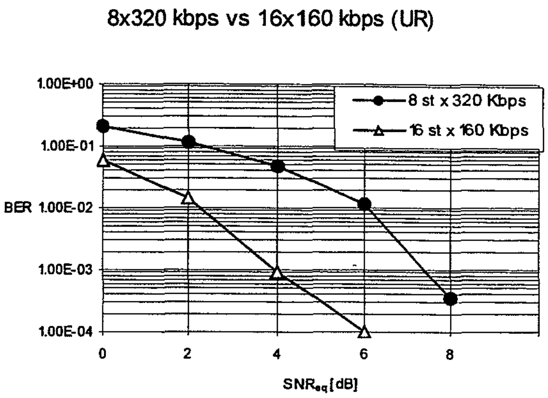

Fig. 7: *BER Performance.*

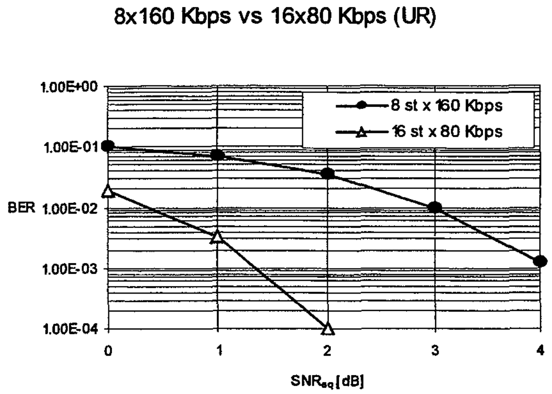

Fig. 8: *BER Performance.*

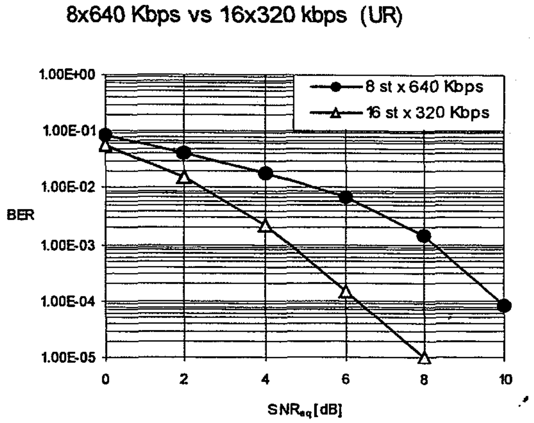

Fig. 9: *BER Performance.*

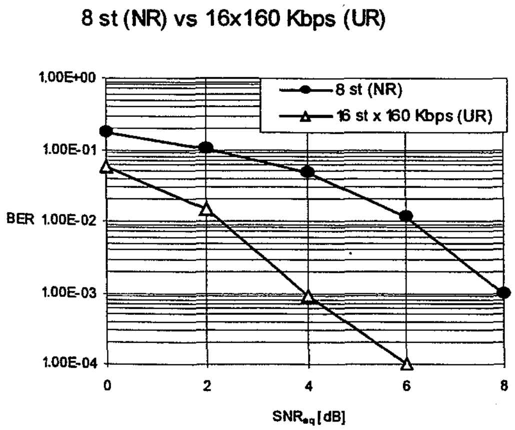

Fig. 10: *BER Performance.*

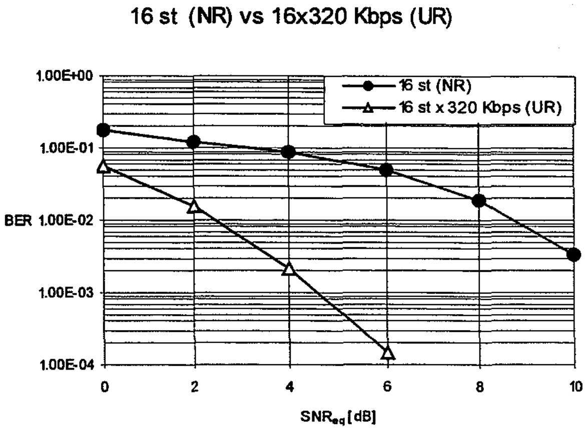

Fig. 11: *BER Performance.*