Comparison of CDMA and OFDM systems for Broadband Downstream Communications on Low Voltage Power Grid

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ABSTRACT

This paper provides a fair comparison between DS-CDMA (Direct Sequence Code Division Multiple Access) and OFDM (Orthogonal Frequency Division Multiplexing) systems for broadband downstream Power Lines Communications (PLCs). Considered schemes seem particularly suitable for high bit rate broadcast flexible communications on low voltage grid in order to guarantee "last mile" access network.
Proposed systems performance is expressed in terms of Bit Error Rate (BER), derived by simulations under the assumptions of frequency-selective multipath fading channel and additive colored gaussian noise according to the in-building networks model, under the same overall working conditions of bandwidth occupation, transmitted power and global data rate.

I. INTRODUCTION

As the number of Internet users increases and the request for multimedia communications grows, the demand for high-rate connections tends to become stronger and stronger, especially for the local access networks, the so-called last mile. Fiber optic utilization would guarantee almost ideal performance but would need huge investments in order to ensure ubiquitous access in all home and offices. As a consequence, alternative viable propagation means and relative techniques have become subjects of a strong research activity in recent years: in particular, an increasing attention is dedicated to low voltage grid as a possible mean for last-mile network [1].
PLC channel is extremely challenging and claims for highly sophisticated communication techniques. Generally, communication is supposed to occur in channel characterized by frequency selective phenomena, presence of echoes, impulsive and colored noise with the superposition of narrow-band interference [2-3].
All these negative features push to consider communication techniques that can effectively face such an hostile environment; as for the majority of the recent works, in this paper DS-CDMA [4-5] and OFDM systems have been considered [6-7]: these techniques are real candidates for future wide-band PLC since they permit to separate overall transmitted data in many parallel independent sub-streams, to implement flexible resources management strategies in order to cope with channel impairments, to provide fine granularity in multimedia services by supporting variable data rates and to achieve remarkable capacity.
Besides sub-streams introduction seems to be a promising solution for the peculiarities of the data traffic to be transmitted: generally, mean data rate during a session may be moderate, even if peaks can seldom occur, with consequent need of additional band resources. Therefore, a flexible assignment of resources, i.e., choosing to give capacity to the active users depending on their effective requests, seems to fit better traffic features.
For what concerns proposed systems, CDMA technique advantages rely in remarkable robustness to narrow-band interference, multiple access with low power spectrum density, so reducing EMC problems. On the other hand, OFDM technique allows to greatly reduce channel equalizer complexity and to increase resistance to narrow-band and impulsive noise; moreover, as reported in this paper, bit loading techniques permit to OFDM system to achieve capacity very near to theoretical limit at the cost of an increase in system complexity. Since these techniques seem both promising for PLC applications, it is necessary to establish fair comparison criteria in order to determine which one is more suitable in the different contexts for a given computational complexity burden: this is one of the two main targets of this paper. The comparisons test between OFDM and CDMA communication systems have been performed assuming same overall bit-rate, same bandwidth occupation, equal transmitted power; besides, coherent phase modulation has been assumed for both systems.

It is important to point out that in this paper the down-stream power line channel is considered and the transmission is performed according to point to multipoint situation, i.e., from master control station to terminal. Moreover, in this paper, different sub-streams allocation policies are considered and compared in order to define smart strategies that can minimize channel impairments.

II. DIRECT SEQUENCE CDMA SYSTEM

Between different Spread Spectrum Multiple Access (SSMA) techniques, Direct Sequence is known as an efficient scheme for communication systems due to its characteristics such as remarkable capacity, narrow-band interference suppression and anti-multipath capabilities: according to this technique, each bit of the signal to be transmitted is multiplied for a pseudonoise sequence whose fundamental element, called chip, is much shorter than the informative bit; as a result, signal bandwidth occupation is increased of a factor equal to the ratio between bit and chip duration, the so-called Spreading Factor (SF). Conventional DS-CDMA receivers consider other users as pure interference and the Multiple Access Interference (MAI) limits the number of active users in relation to a specified bit error rate (BER).

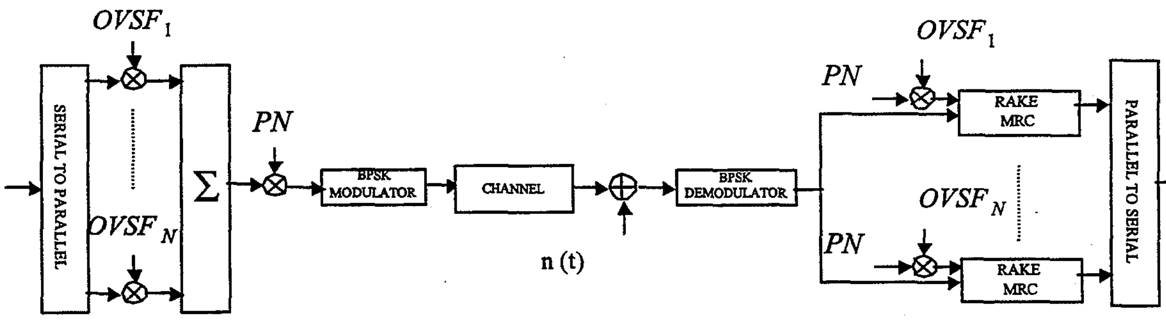

Fig. 1: DS-CDMA System Block Diagram.

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 interference suppression property involved by this technique introduction.

Proposed multiple access scheme is based on joint utilization of Orthogonal Variable Spreading Factor (OVSF [6]) and random scrambling codes: firstly, each global bit stream is divided in N parallel sub-streams, orthogonally separated each others by a channelisation operation performed by multiplying them with an individual orthogonal OVSF code; in the second step all the sub-streams 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 possible users. Transmitted signals are supposed to be BPSK modulated. As it is known, joint use of this two kinds of codes help obtaining 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, all the data streams can be assumed to be effectively synchronized, so completely deploying MAI impairments mitigation properties. Finally, rake diversity reception is adopted: each receiver has N parallel Maximum Ratio combining (MRC) rake blocks to detect all the sub-streams in which transmitted signal has been split. DS-CDMA communication scheme is described in Fig. 1.

III. OFDM SYSTEM

Multi-carrier transmission techniques are based on the idea of partitioning the overall bandwidth in order to create many sub-channels, each characterized by its personal carrier: this solution takes to obtain almost ideal condition of propagation for all the informative data flows even if the overall channel is characterized by colored noise and frequency selectivity; as a consequence, since Inter-Symbol Interference (ISI) impairments are negligible, channel equalizer block can be dramatically simplified or, ideally, suppressed. Moreover, this modulation technique permits to achieve data rate near to channel capacity if channel impulse response and noise power density spectrum are known.

OFDM technique can be considered as an evolution of multi-carrier techniques: it is characterized by very high spectral efficiency thanks to orthogonal sub-carriers utilization; sub-carriers orthogonality condition is guaranteed if frequency spacing is at least equal to inverse of OFDM symbol duration.

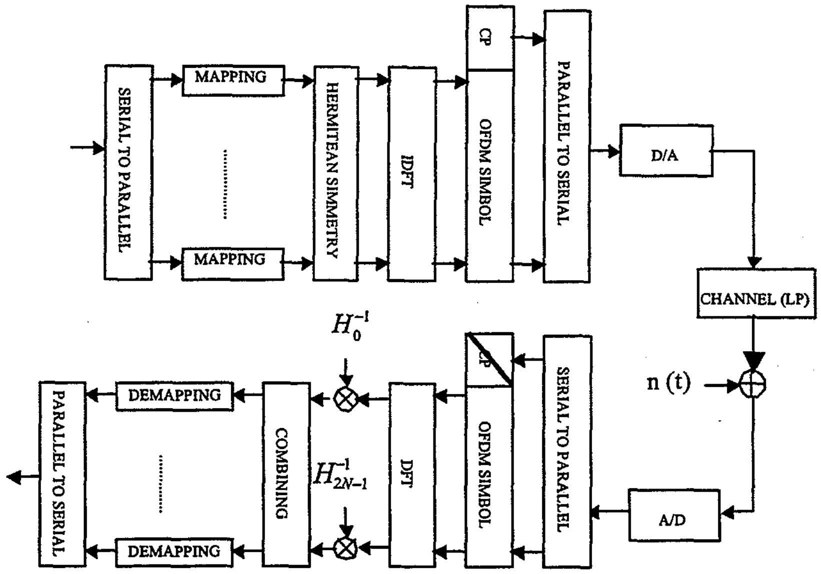

Fig. 2: OFDM System Block Diagram.

Discrete Fourier Transform (DFT) utilization permits to perform modulation and demodulation by baseband processing: particularly, modulation operation, that is symbol mapping upon single sub-carrier, is accomplished by inverse Fourier Transforming (IDFT) of 2N hermitean complex symmetric values; these values are generated from N complex symbol in order to transmit a real signal modulated upon N sub-carriers.
During propagation, ISI arises because of delay spread while channel distortion takes to loose orthogonality between sub-carriers, so creating Inter-Channel Interference (ICI). Both impairments can be faced by cyclic prefix (CP) introduction: in particular, if CP length is chosen to be at least equal to delay spread í, bandwidth efficiency loss is equal to í / (í + 2N). CP introduction takes to obtain at the receiver cyclic convolution of Channel Impulse Response and transmitted signal so that it is relatively easy to eliminate CP from the received signal. Moreover, after DFT, only a 1-tap equalizer is required for the received signal.
Finally, it is worth stressing that Bit-Loading (BL) techniques utilization permit to transmit more bits in the sub-channels characterized by less attenuation and interference and not to use less favorable sub-bands. This approach permits to achieve capacity near to theoretical limit even if finite granularity in choosing signal constellation and in sub-channel bandwidth occupation take to suboptimum results. It is important to point out that in OFDM approach BER minimization is performed assuming whole bitrate and transmitted power constant and using a margin adaptive algorithm [8]. OFDM communication scheme is described in Fig. 2.

IV. WORKING CONDITIONS AND COMPARISON CRITERIA

In this paper the considered propagation environment is wired communication channel inside of buildings as described in [3]. PL channel impedance is highly varying with frequency, ranging between a few Ohm and a few kOhm. Moreover, load conditions changes and discontinuities in branch cables can cause reflection and echoes. Peaks in the impedance characteristics may occur at certain frequencies. As a result, PL channel can be considered as a multipath propagation environment with deep narrowband notches in the frequency response.
Power lines noise spectrum is highly varying with frequency and time; in the considered environment three kinds of noise can be identified: Additive Colored Gaussian Noise with spectral power density decaying with frequency, narrow-band interference which can be modeled as single tones in frequency domain, and impulse noise: in particular, impulse noise are strong peaks whose duration could be equal to some ms and mean time between occurrence to several s. During such strong peaks, information bits are damaged 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. Finally, channel characteristics are assumed not to show fast variations in time with respect to the bit epoch so that channel can be considered as quasi-stationary. In

order to effectively represent channel characteristics, echo model parameters set, provided in [3], 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.
In performing our simulations the following conditions have been assumed:

- PLC channel ranging from 1 MHz to 21.480 MHz, i.e., bandwidth occupation equal to 20.480 MHz;
- overall maximum bit rate equal to 10.240 MHz;
- coherent phase modulation and rectangular pulse shaping for all the considered signals;
- perfect power matching, i.e. ideal power transfer.

For what concerns DS-CDMA systems the following conditions have been supposed:

- considered substreams bit-rate equal to 40, 160, 320, 640 and 2560 kbit/s;
- spreading through a OVSF code, followed by a random scrambling code; the spreading factor of the OVSF code is variable according to the bit rate, i.e. SF=4 for a bit rate of 2560 kbit/s and SF=256 for 40 kbit/s.

It is worth stressing, that, in the proposed scheme, the same random code is supposed to be used for all the substreams: if different informative traffic flows are supposed to be transmitted over the same link simultaneously, it would be possible to differentiate informative streams by means of different random codes utilization. Anyway, this solution is not considered in present work.
On the other hand, OFDM systems are based on the following assumptions:

- considered subchannels number equal to 64 and 256;
- bit loading technique based on the utilization of constellations formed by 2, 4 and 8 symbols; besides the power is distributed between the subchannels s o that each bit has the same energy.

There are several comparison study of CDMA and OFDM systems [9-10]: in these papers, the two systems have been compared under the same conditions of bandwidth occupation, overall transmitted power and global data rate. The BER performance of the considered systems have been evaluated for different values of the Signal to Noise Ratio (SNR): in particular SNR is defined for each substream, that is to say for each informative flow, as:

$$SNR_{flow} = \frac{S_0}{N} = \frac{E_s R}{N_{0eq} W} \qquad (1)$$

where S_0, N, E_s, R, W and N_{0eq} are signal and noise power, symbol energy and rate, occupied bandwidth and the equivalent mean noise power density, respectively.
In the OFDM systems, overall SNR is equal to SNR_{flow}: in fact, if the number of sub-streams is doubled, also symbol time is doubled, so that transmitted power is the same. On the contrary, in CDMA systems, the number of sub-streams can be doubled if the SF is doubled, that is to say the symbol time is halved. As a consequence, overall transmitted power depends on the number of active sub-streams: in particular, overall SNR is equal to $SNR_{flow} \cdot SF$. In order to have a fair comparison between the two systems, same power is assumed to be transmitted, that is to say that overall SNR is assumed equal for both systems.

V. NUMERICAL RESULTS

In this section, performance of the proposed systems are described in different environments conditions and for several system load configurations.
In Figs. 3-5, CDMA system is evaluated for different sub-streams configurations: in particular, in Fig. 3, single sub-stream system is considered, showing benefits caused by greater spreading factor. In Figs. 4-5, full load systems are considered in the case of uniform and non uniform rate allocation: it can be deduced that, even if same power is transmitted for all the systems, the strategy of dividing the whole data flow in as many as possible low rate sub-streams is the most profitable. Moreover, it is evident that the choice of uniformly splitting overall rate take to obtain remarkably better performance [11].
While in Fig. 6 noise amplitude spectrum is reported, in Figs. 7-8 the BER performance of all the different sub-channels of the proposed OFDM systems is evaluated with and without BL technique application in the case of 64 and 256 sub-streams: in both cases, OFDM technique with no BL leads to poor performance for the sub-streams whose band are located over the narrow-band interference; on the contrary, BL technique introduction allows to transmit only over favorable channels, avoiding bands characterized by worse propagation conditions. It is worth underlining that for the most favorable channels 4 and 8 PSK constellations are used.
Finally, in Figs. 9-10 CDMA and OFDM with and without BL systems are compared for 64 and 256 sub-streams: in particular, DS-CDMA system achieves better performance than OFDM with no BL but is greatly overcome by OFDM system with BL. OFDM capability of select channels and modulations seem to be the best solution in the considered environment, at a cost of more complex channel estimation.

VI. CONCLUDING REMARKS

In this paper, a fair comparison between DS-CDMA and OFDM systems for broadband downstream PLCs has been provided under the same overall working conditions of bandwidth occupation, transmitted power and global data rate. BL technique introduction allows OFDM to achieve remarkable performance and high flexibility in resources management. On the contrary, CDMA guarantees good performance and satisfactory allocation policies with low complexity receiver.

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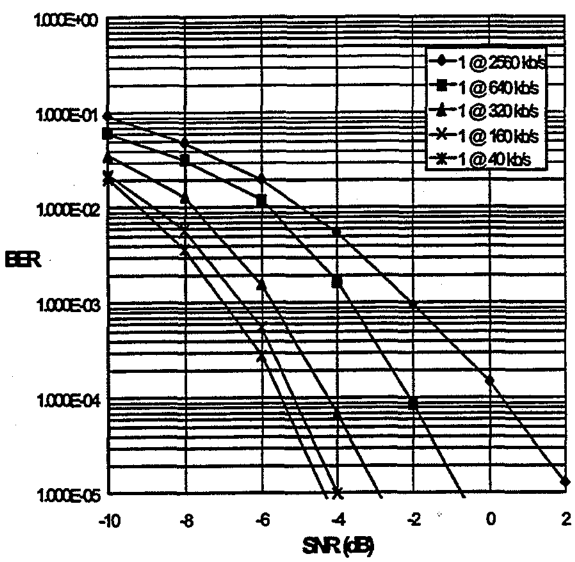

Fig. 3: BER Comparison.

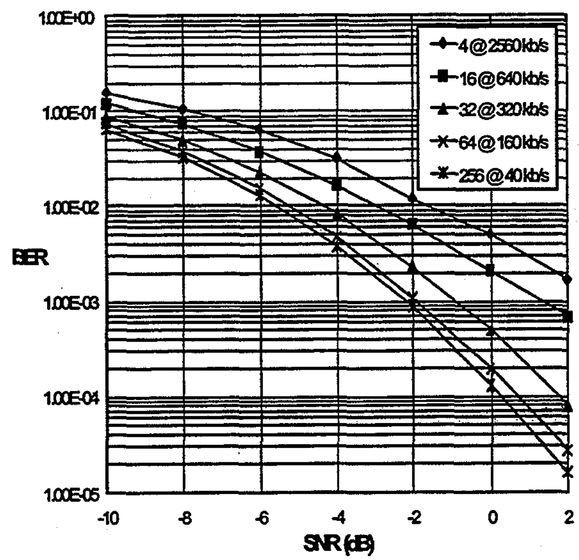

Fig. 4: BER Comparison.

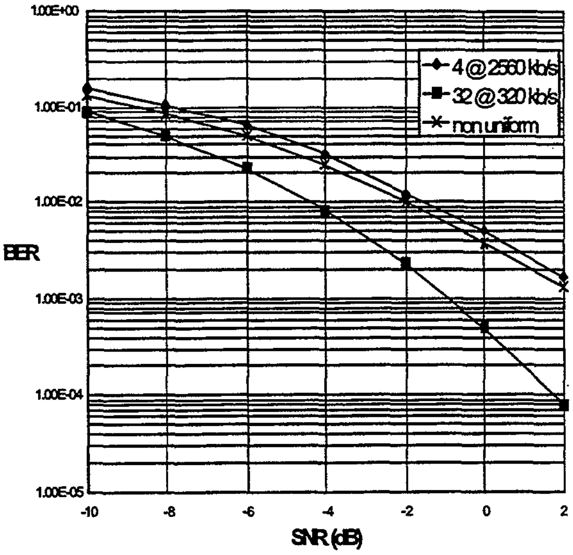

Fig. 5: BER Comparison.

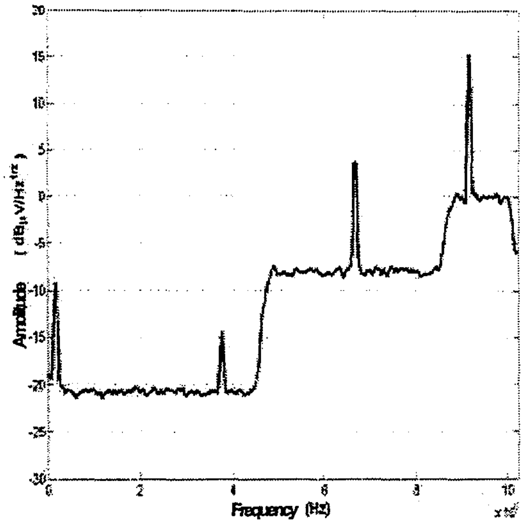

Fig. 6: Noise Amplitude Spectrum.

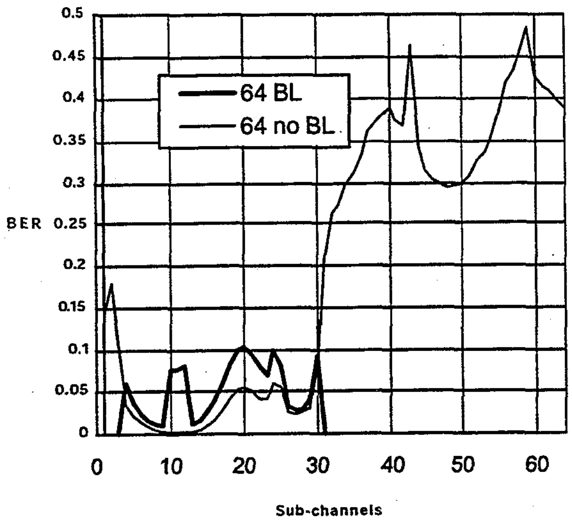

Fig. 7: BER Comparison.

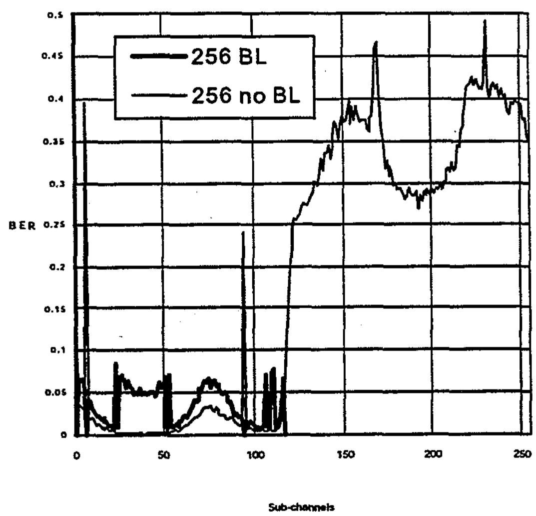

Fig. 8: BER Comparison.

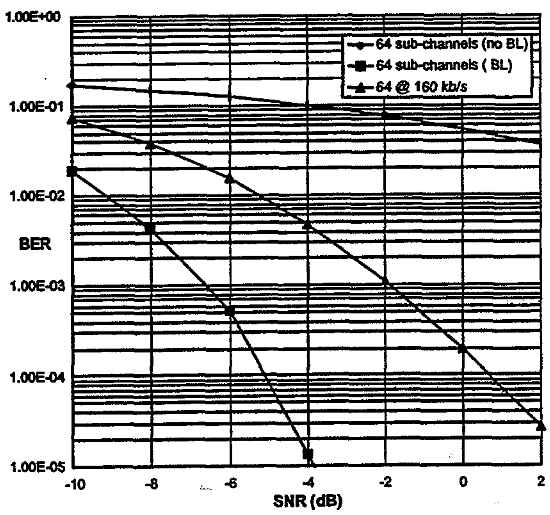

Fig. 9: BER Comparison.

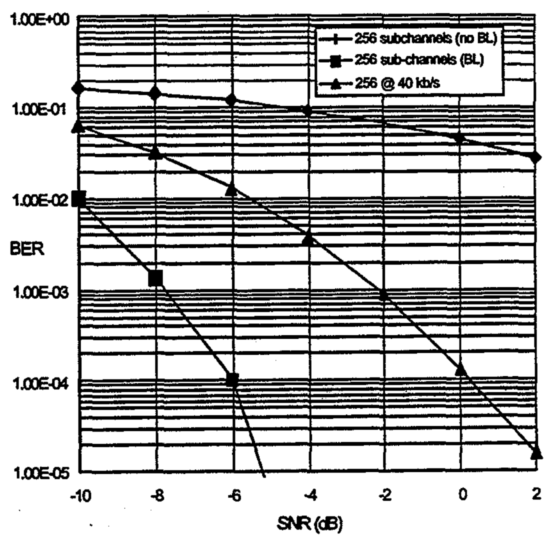

Fig. 10: BER Comparison.