Combined Phase Compensation and Power Allocation Scheme for OFDM Systems

Wladimir Bocquet
France Telecom R&D Tokyo
3-1-13 Shinjuku, 160-0022
Tokyo, Japan
Email: bocquet@francetelecom.co.jp

Kazunori Hayashi and Hideaki Sakai
Graduate School of Informatics, Kyoto University
Yoshida-Honmachi, 606-8501
Kyoto, Japan
Email: {kazunori, hsakai}@i.kyoto-u.ac.jp

***Abstract*— This paper proposes a novel transmit power allocation combined with the phase compensation for OFDM system. This technique consists of adapting the power allocation and the phase compensation in the frequency domain depending on the channel variations. Optimization process is based on the optimality of the global Bit Error Rate (BER). Simulation results show significant performance gains can be obtained by the proposed scheme regardless of baseband modulation schemes.**

***Keywords-* OFDM, phase compensation, Lagrangian method, global BER optimization.**

I. INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) has received considerable interest over the last decade for its advantages in high-bit rate transmissions over frequency slective fading channels. In OFDM systems, the input high-rate data stream is divided into many low-rate streams [1], so called subcarriers, that are transmitted in parallel. Robustness to multi-path delay is obtained when appropriate guard interval is inserted in the transmitted frame. In frequency selective fading environment, fading conditions strongly affect the channel gains of each subcarrier. In this paper, we propose to combine the phase compensation at the transmitting part and the adaptation of the transmit power in the frequency domain in terms of channel condition of each load subcarrier. The proposed method consists of grouping a certain number of subcarriers and local power allocation in each subcarrier group. In addition, the power allocation value is combined with a phase, which compensates the channel selectivity in the frequency domain. The rest of the paper is organized as follows. In Section II we review the system model. In Section III, we introduce the estimate value of BER for channel encoded sequence and we describe in detail the proposed power adaptation scheme in the frequency domain. In addition, we highlight the combination of the phase compensation with the power adaption. Section IV gives the experimental results over QPSK and QAM modulations. Finally, conclusions are drawn in Section V.

II. SYSTEM DESCRIPTION

The principle of OFDM transmission scheme is to reduce bit rate of each sub-carrier [1] and also to provide high bit rate transmission by using a number of those low bit rate sub-carriers. Frequency bandwidth is divided into small ranges and each of them is handled by these low rate sub-carriers. The subcarriers are orthogonal to each other. To obtain this property, the subcarrier frequencies must be spaced by a multiple of the inverse of symbol duration. Multi-carrier modulation system can provide immunity against frequency selective fading because each carrier goes through non-frequency selective fading. However, the channel must be estimated and corrected for each sub-carrier.

Figure 1 shows the transceiver of the conventioanl transmission with phase compensation at the transmitting part.

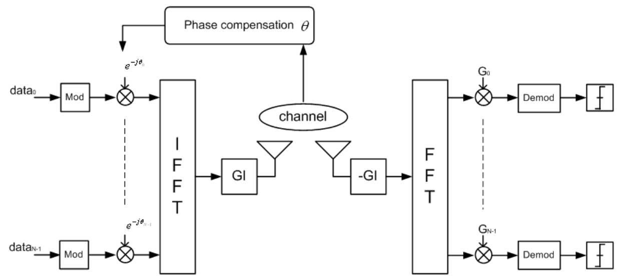

Fig. 1. Conventional transceiver with phase compensation

A. OFDM transmitter

The High-speed binary data are first encoded (convolutional coding) and modulated (QPSK, 16-QAM or 64-QAM). Then data are converted to parallel low speed modulated data streams and fed to several subcarrier channels. The modulated signals are frequency-division multiplexed by an N-point inverse discrete Fourier transform (IDFT). The resulting OFDM signal is then converted into an analog signal by a digital-analog (D/A) converter, up-converted (U/C) to the RF band and transmitted. For reliable detection, it is typically necessary that the receiver knows the wireless communication channel and keeps track of phase and amplitude variations. To enable the estimation of the wireless communication channel, the transmitter occasionally sends known training symbols. For instance, a preamble, which includes channel training sequences, is added to every packet in IEEE 802.11 WLAN standards [2]-[3]. Consider an OFDM system that transmits N modulated data symbols in the i-th OFDM symbol period through N sub-channels. For the i-th block symbol, the transmitted baseband OFDM signal is expressed as [4]:

$$s_{i,n} = \frac{1}{\sqrt{N}}.\sum_{k=0}^{N-1} x_{i,k}.\exp\{-j\theta_k\}.\exp\left\{j\frac{2\pi.nk}{N}\right\} \quad (1)$$

where θ_k is the phase compensation of the channel on the k-th subcarrier and $x_{i,k}$ is the modulated data symbol of the i-th OFDM symbol. To combat inter symbol interference (ISI) and inter carrier interference (ICI), guard interval (GI) [5] such as cyclic prefix (CP) or zero padding (ZP) is added to the OFDM symbols. In the case of the CP, the last N_g samples of every OFDM symbol are copied and added to the heading part. The transmitted signal can be described as follow:

$$\tilde{s}_{i,n}^{(p)} = \begin{cases} s_{i,N-N_g+n}^{(p)} & \text{for } 0 \leq n < N_g \\ s_{i,n-N_g}^{(p)} & \text{for } N_g \leq n < N + N_g \end{cases} \quad (2)$$

B. Channel representation and detection scheme

We assume that the system is operating in a frequency selective Rayleigh fading environment [6] and the communication channel remains constant during a packet transmission. Data frame duration is assumed to transmit within the coherent time of the wireless system. In this case, channel variations remain constant during on frame transmissions and may change between consecutive frame transmissions. We suppose that the fading channel can be modeled by a discrete-time baseband equivalent $(L-1)$-th order finite impulse response (FIR) filter where L represents time samples corresponding to the maximum delay spread. In addition, an Additive White Gaussian Noise (AWGN) with independent and identically distributed (iid) zero mean, complex Gaussian elements is assumed.

C. OFDM receiver

At the receiver, signals are passed through a down- converter (D/C) and a analog to digital converter with rate $1/Ts$. Then, the GI is removed and the N-point Discrete Fourier Transform (DFT) is performed. Since channel parameters suppose to be frequency selective, detection has to be done per subcarrier. Finally, de-mapping, de-interleaving and channel decoding are performed on the data streams and the resulting data are combined to obtain the original binary sequence.

When the maximum delay spread does not exceed GI, since ISI does not occur on OFDM symbol basis, the frequency domain OFDM signal after removal of GI is described by:

$$y_{j,m} = h_m \times x_{j,m} + n_{j,m} \quad (3)$$

where $y_{j,m}$ is the received signal for the j-th OFDM symbol and the m-th sub-carrier and h_m is the channel parameter for the m-th sub-carrier. In addition, $n_{j,m}$ denotes the additional Gaussian noise. Thus it results in a frequency-flat-fading signal model per sub-carrier.

D. Phase compensation and equalization

As described previously, the channel in a multipath environment is frequency selective faded. The main impact concerns the equalization (in the case of appropriate guard interval selection). The channel representation in the frequency domain can be represented by:

$$h_m = |h_m|.e^{j\theta_m} \quad (4)$$

So, we multiply each load subcarrier by the value $e^{-j\theta_m}$.

At the receiving part, due to the structure of the proposed scheme, the complexity part of the equalization is highly reduced. It simply consists of the modulation adaptation (especially for the QAM modulations) including the channel variation. the channel equalization coefficient can be written as:

$$G_m = (\sqrt{p_m}.|h_m|)^{-1} \quad (5)$$

where $G_m \in \Re^+$ denotes the equalizer value for the m-th subcarrier.

III. Power Allocation Scheme

A. Proposed principle

Figure 1 shows the main features of the proposed system. The basic principle of the combined phase compensation and power allocation for multi-carrier signal is to perform phase estimation and compensation at the transmitting part and frequency domain optimization of the transmit power in function of the channel state information (CSI) and the expression of the global BER for the different modulations. The Lagrangian optimization method will be proposed to obtain analytical value of the power allocation for each load subcarrier. Furthermore, constraint is added in order to keep constant the global transmit power at the transmitting part. The optimal case is to consider the power allocation scheme through one multi-carrier symbol which is represented by N elements. However, due to the computation complexity to perform power allocation scheme, we propose to perform it through a limited number of subcarrier denoted N_s and then we repeat the allocation scheme N/N_s times. The total power resource assigned by the proposed algorithm satisfies the simple relation that the total transmit power is kept constant. The phase analysis is obtained by estimating the phase rotation for each load subcarrier and the compensation is performed by simply multiplying the conjugate of the phase on each load subcarrier.

B. Bit Error Rate approximation

We next list the assumptions adopted in this paper. The channel is frequency flat, and remains invariant per frame, but is allowed to vary from frame to frame. This corresponds to

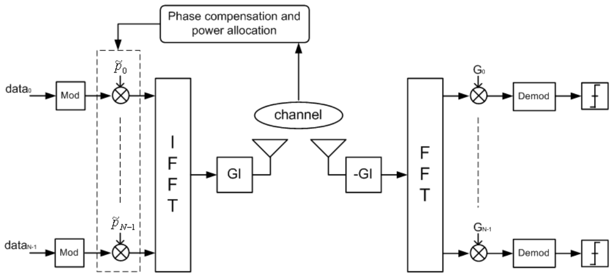

Fig. 2. Proposed transceiver with phase compensation

a block fading channel model, which is suitable for slowly-varying channels. As a consequence, power allocation is adjusted on a frame-by-frame basis. Perfect channel state information (CSI) is available at the receiver. The corresponding power selection is fed back to the transmitter without any error and latency. The assumption that the feedback channel is error free and has no latency, could be at least approximatively satisfied by using a fast feedback link with powerful error control for feedback information. Further considerations on system design with delayed or noisy CSI will be in the future considered.

For flat fading channel adhering the previous assumptions, the channel characteristics is captured by the received SNR. The received SNR is a function of the variance of the noise, the channel state information, and the transmit power. Since the channel varies from frame by frame, the approximated BER can be described as a function of the received SNR (i.e. transmit power for each transmit antenna and channel condition). In [7], a general formula describing this relation in a flat fading channel environment is proposed. Typically, the BER for any modulation can be simply estimated as follows:

$$f(\beta_m, p_m) \approx a \times \exp\big\{ - b \times \beta_m \times p_m \big\} \tag{6}$$

with:

$$\beta_m = \frac{|h_m|^2}{(2^{N_m} - 1).\sigma_n^2} \tag{7}$$

where N_m, σ_n^2, and p_m are respectively the number of bits per symbol, the variance of the noise and the transmit power on the m-th subcarrier.

Table I summarizes the heuristic value of the parameters a and b defined in (5) for several modulations. Parameters are obtained by fitting (5) to simulated data.

TABLE I

TRANSMISSION MODES FOR DIFFERENT MODULATION

Modulation	QPSK	16-QAM	64-QAM
Rate (bits/symb.)	2	4	6
a	0.2	0.2	0.15
b	1.66	1.73	1.68

C. Power adaptation

Proposed power allocation consists of optimizing the BER function described below by estimating optimum power allocation [8]. Power allocation algorithm determines how to allocate the power in the frequency domain. The global power resource assigned by the proposed algorithm satisfies the simple relation that the total transmit power is kept constant. Principle is described in this section for one set of subcarrier. In practical implementation (i.e. for simulation), proposed method are repeated N/N_s times. This constraint for each selected subset of size N_s can be described by:

$$\sum_{m=0}^{N_s-1} p_m = N_s.\overline{P} \tag{8}$$

where $\overline{P}_m$ denotes the average Transmit Power on the subcarrier m and N_s represents the size of the cluster.

The average BER becomes minimal when the BER is minimized for each given channel state. Equivalent mathematical representation can be given by:

$$\begin{cases} \text{min } f(\beta_m, p_m) \\ \\ \text{subject to:} \\ \sum\limits_{l=0}^{N_s-1} p_m = N_s.\overline{P} \end{cases} \tag{9}$$

One possibility to solve this optimization problem is to apply the Lagrangian procedure on each cluster. The processing can be described as:

$$\begin{aligned} J(p_0, ..., p_{N_s-1}) = \frac{1}{N_{cl}} \sum_{l=0}^{N_s-1} f(\beta_m, p_m) \\ + \lambda \times (\sum_{l=0}^{N_s-1} p_m - N_s \times \overline{P}) \end{aligned} \tag{10}$$

Then, optimal solutions are obtained by solving for each transmit antenna:

$$\begin{cases} \frac{1}{N_s}.\frac{\partial}{\partial p_m}\left(\sum\limits_{l=0}^{N_s-1} f(\beta_m, p_m)\right) + \lambda = 0 \\ \\ \sum\limits_{l=0}^{N_s-1} p_m - N_s.\overline{P} = 0 \end{cases} \tag{11}$$

By introducing the explicit estimation of the BER in the set of equations, we can write for each transmit antenna that:

$$\begin{cases} \frac{-a.b.\beta_m}{N_s} \times \exp(-b.\beta_m.p_m) + \lambda = 0 \\ \\ \sum\limits_{l=0}^{N_s-1} p_m - N_s.\overline{P} = 0 \end{cases} \tag{12}$$

After calculation and rearrangement, we finally obtain the following general solution:

$$p_m = \left[1 + \sum_{\substack{u=0 \\ u\neq m}}^{N_s-1} \frac{\beta_m}{\beta_u}\right]^{-1} \times \left[N_s.\overline{P} + \frac{1}{b} \times \sum_{\substack{u=0 \\ u\neq m}}^{N_s-1} \frac{1}{\beta_u} \times \log\left(\frac{\beta_m}{\beta_u}\right)\right] \quad (13)$$

Due to the specificity of the Lagrangian calculation (only mathematical solutions are obtained), we need to add a constraint when the output of the Lagrangian optimization does not reflect any physical solution, typically when we obtain: $p_m \leq 0$. In this case we propose to apply the conventional scheme.

We repeat the power allocation process for each cluster of subcarrier which composes the OFDM symbol. In the proposed scheme, the channel variation in the frequency domain is available both at the transmitter and at the receiver parts. So, we propose to weight the value of the power distribution by the inverse of the phase coming from the channel variations. In that case, the coefficient which is multiplied on each load subcarrier is equal to:

$$\widetilde{p}_m = \sqrt{p_m}.e^{-j\theta_m} \quad (14)$$

where $\widetilde{p}_m$ is the modulated power coefficient on the m-th subcarrier.

IV. Experimentation

We now evaluate the performance of the proposed power allocation method for multi-carrier scheme in a mutli-path fading environment. Main simulation parameters are introduced in the Table II. We assume perfect knowledge of the channel variations both at the transmitting and receiving parts. For all simulations, an exponential model with 1-dB decay multi-path model is assumed. Carrier frequency is equal to 2.4GHz, the IFFT/FFT size is 64 points and the guard interval is set up at 16 samples. Effect of proposed scheme for several cluster sizes and different modulations is highlighted.

TABLE II
SIMULATION PARAMETERS

Carrier Frequency	2.4 GHz
Bandwidth	20 MHz
Modulations	QPSK, 16-QAM, 64-QAM
Channel encoder	No code
Channel estimation	Perfect CSI
Number of data subcarrier	64
Guard Interval length	16
Channel model	10-path, Rayleigh Fading
Sample period	0.05μs
Number of data packet	50
Cluster size (N_s)	2, 4, 8

Performance evaluation is presented in the figure 3 for the case of QPSK modulation. The performances of both conventional scheme and proposed method are plotted. In Fig. 3, the conventional scheme represents the phase compensation at the transmitting part without any power allocation. In addition, effect of the grouping size is highlighted in this figure. Larger is the group selection, better is the BER performance. However, a trade-off needs to be accepted between the complexity and the performance. Size of the group selection directly affects the complexity of the proposed system as described in Eq. 11. The different summations and ratios that are estimated, depend on the size of group selection. Simulation results show that at average BER=10^{-5},

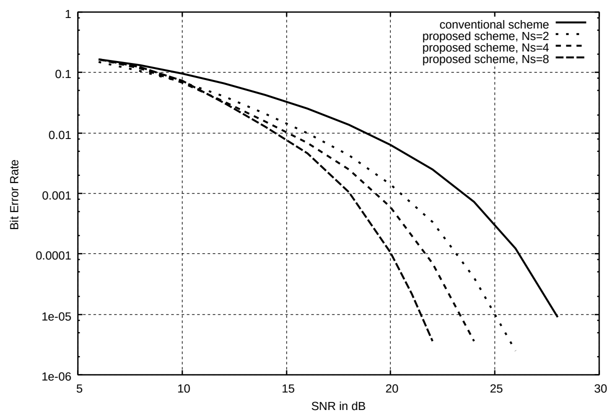

Fig. 3. Performance Simulation for QPSK modulation

respectively, 3, 5, and 7 dB gains are obtained for the group selection size $N_s = 2$, $N_s = 4$ and $N_s = 8$.

In the Fig. 4, results are presented for the case 16-QAM

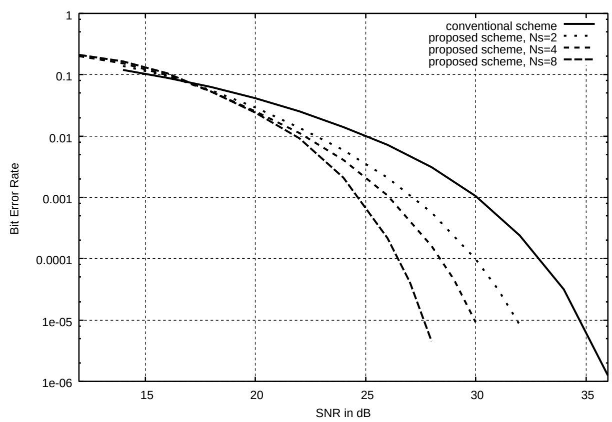

Fig. 4. Performance Simulation for 16-QAM modulation

modulation for different group selection. Gains obtained by performing proposed power allocation scheme with ordering are equal to 2.8dB for $N_s = 2$, 4.4dB for $N_s = 4$ and 6.4dB for $N_s = 8$ at average BER=10^{-4}.

Average BER versus the total SNR are presented in the Fig. 5 for the case 64-QAM modulation. Gain obtained by performing proposed power allocation scheme becomes relatively significant. At average BER=10^{-4}, 3dB for $N_s = 2$, 4.5dB for $N_s = 4$ and 6.2dB for $N_s = 8$ gains are obtained.

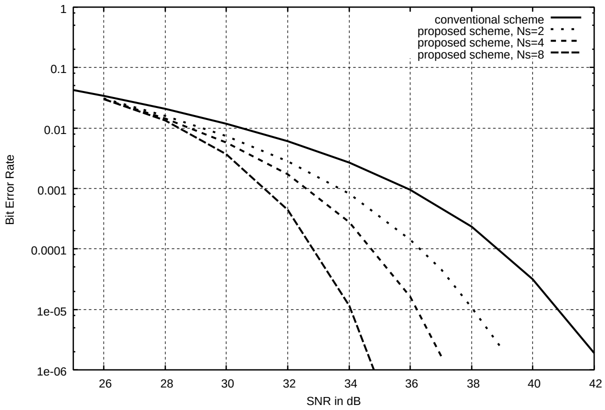

Fig. 5. Performance Simulation for 64-QAM modulation

V. CONCLUSION

In this paper, we have presented an original method to combine a power allocation with a phase compensation. The basic procedure consists of allocating transmit power in function of the channel conditions and the global BER requirement and a phase compensation. The second part of the proposed method (i.e. phase compensation) is obtained by channel estimation. The simulation results have shown promising results in term of BER for several sets of cluster configuration and different modulations. In addition, this proposed system can be adapted to any type of detection scheme [9] and any type of coding scheme such as turbo code [10] or low density parity code [11]-[12].

REFERENCES

[1] L.J. Cimini, "Analysis and simulation of digital mobile channel using orthogonal frequency division multiple access," *IEEE Tans. Commun.*, pp.665–675, 1995.

[2] IEEE 802.11a standard, ISO/IEC 8802-11, 1999.

[3] Draft IEEE 802.11g standard, Further Higher Speed Physical Layer Extension in the 2.4GHz Band, 2001.

[4] R. Van Nee et al., OFDM for wireless multimedia communications, Artech House, 2000.

[5] B. Muquet et al., "Reduced complexity equalizers for zero-padded OFDM transmissions," *Proc. of the ICASSP*, Istanbul, Turkey, 2000.

[6] J. Proakis, Digital Communications, 3rd ed. Singapore: McGraw-Hill, 1995.

[7] X. Qiu et al., "On the performance of adaptive modulation in cellular system," *IEEE TRANS. On Communications*, vol.47, no.6, pp.884–895, 2005.

[8] Zh. Jiang et al., "Max-Utility wireless resource management for best-effort traffic," *IEEE Wirel. Commun. Mag.*, vol.4, no.1, pp.100–111, 2005.

[9] H. Kawai et al., "Likelihood Function for QRM-MLD Suitable for Soft-Decision Turbo Decoding and Its Performance for OFCDM MIMO Multiplexing in Multipath Fading Channel," *IEICE Trans. Commun. Mag.*, vol.E88, no.1, pp.47–57, 2005.

[10] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near shannon limit error-correcting coding and decoding: Turbo-codes," *in Proc. IEEE International Conference on Communications (ICC'93)*, Geneva, Switzerland, May 1993, pp. 1064–1070.

[11] R. Gallager, "Low Density Parity Check codes," *Cambridge, MIT press*, 1963

[12] G. E. Oien, H. Holm, and K. J. Hole, "Adaptive Coded Modulation With Imperfect Channel State Information: System Design and Performance analysis Aspects," *in Proc. IEEE Int Symposium Advances in Wireless Communications*, Victoria, Canada, pp.19–24, Sept. 2002.