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COMBINED FREQUENCY AND SPATIAL DOMAINS POWER DISTRIBUTION FOR MIMO-OFDM TRANSMISSION

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ABSTRACT

In this paper, we propose to adapt simultaneously the transmit power both in the spatial and frequency domains using a heuristic expression of the bit error rate (BER) for each subcarrier and transmit antenna. The proposed method consists of grouping a certain number of subcarriers and performing local power adaptation in each subcarrier group and transmit antenna. The subcarrier grouping is performed in such a way that equalizes the average channel condition of each subcarrier group. The grouping and the local power adaptation allow us to take advantage of the channel variations and to reduce the computational complexity of the proposed power distribution scheme. With the simplicity of the heuristic BER expression, we can obtain a closed form expression of the transmit power to be allocated. Simulation results show significant performance gain in term of BER compared to the equal power distribution.
Keywords- OFDM, MIMO, Lagrangian method, global BER optimization.

I INTRODUCTION

Orthogonal Frequency Division Multiplexing (OFDM) [1] is a popular method for high data rate wireless transmission. Combining OFDM with antenna arrays at the transmitter and receiver enhances the capacity gain. Robustness of MIMO-OFDM transmission 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 and transmit antenna [2]. In this publication, we propose to combine the adaptation of the transmit power in the frequency and spatial domains in terms of BER performance. The proposed method consists of grouping a certain number of subcarriers and then perform local power adaptation simultaneously in each subcarrier group and all the transmit antennas. The rest of the paper is organized as follows. In Section II we review the conventional MIMO-OFDM scheme. In Section III, we introduce the estimate value of BER for channel encoded sequence and we describe in detail the proposed power adaptation scheme simultaneously in the frequency and spatial domains. Grouping method and calculation of the power allocation in the frequency and the spatial domains will be explained. Section IV gives the experimental results over QPSK and QAM modulations, different antenna configurations, and several coding gains. Finally, conclusions are drawn in Section V.

II SYSTEM DESCRIPTION

A MIMO OFDM transmit signal

The principle of OFDM transmission scheme [1] is to reduce bit rate of each sub-carrier and also to provide high bit rate transmission by using a number of those low bit rate subcarriers. OFDM system can provide immunity against frequency selective fading because each carrier goes through non-frequency selective fading. Given the system description of the OFDM system, we can develop a MIMO-OFDM signal model. In this paper, we will need both time-domain and frequency-domain models. Suppose that a communication system consists of N_t transmit (TX) and N_r receive (RX) antennas, denoted as $N_t \times N_r$ system, where the transmitter at a discrete time interval t sends an N_t-dimensional complex vector and the receiver receives an N_r-dimensional complex vector. An OFDM system [1] transmits N modulated data symbols in the i-th MIMO-OFDM symbol period through N sub-channels. The transmitted baseband MIMO-OFDM signal for the i-th block symbol, is expressed as

$$s_{i,k}^{(l)} = \frac{1}{\sqrt{N}} \cdot \sum_{m=0}^{N-1} \sqrt{p_{l,m}} \cdot x_{i,m}^{(l)} \cdot \exp\left\{ j \frac{2\pi \cdot m \cdot k}{N} \right\} \quad (1)$$

where $x_{i,m}^{(l)}$ and $p_{l,m}$ are respectively the modulated data symbol and the transmit power on the l-th transmit antenna for the i-th OFDM symbol on the m-th subcarrier. To combat inter symbol interference (ISI) and inter carrier interference (ICI), guard interval (GI) [3] such as cyclic prefix (CP) or zero padding (ZP) is added to the OFDM symbols. In the case of CP, the last N_g samples of every OFDM symbol are copied and added to the heading part. The transmit signal can be described as follows:

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

B MIMO OFDM received signal

We assume that the system is operating in a frequency selective Rayleigh fading environment [4] and the communication channel remains constant during a packet transmission. One data frame duration is assumed to transmit within one coherent time of the wireless system. In this case, channel characteristics remain constant during one 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 N_r independent and identically distributed (iid) zero mean, complex Gaussian elements is assumed. When the maximum delay spread does not exceed GI, since ISI does not occur on MIMO OFDM symbol basis, the frequency domain MIMO OFDM signal after removal of GI is described by:

$$y_{i,m}^{(q)} = \sum_{l=0}^{N_t-1} h_m^{(q,l)} \cdot \sqrt{p_{l,m}} \cdot x_{i,m}^{(l)} + n_{i,m}^{(q)} \tag{3}$$

where $y_{j,m}^{(q)}$ is the received signal at the q-th received antenna for the i-th OFDM symbol and the m-th sub-carrier and $h_m^{(q,l)}$ is the channel parameter from the l-th transmitting antenna to the q-th receiving antenna which composes the MIMO channel matrix. In addition, $n_{j,m}^{(q)}$ denotes the AWGN for the q-th received antenna.

In this paper, we limit the study to the linear detection scheme. Thus, output of the equalizer can be described by:

$$\mathbf{z}_{i,m} = \mathbf{G}_m \cdot \mathbf{y}_{i,m} \tag{4}$$

where $\mathbf{z}_{i,m} = [z_{i,m}^{(0)}, \cdots, z_{i,m}^{(N_t-1)}]^T$ and $\mathbf{y}_{i,m} = [y_{i,m}^{(0)}, \cdots, y_{i,m}^{(N_r-1)}]^T$ respectively denote the output of the equalizer and the received signal. In the case of zero forcing (ZF) detection, the equalizer elements are equal to

$$\mathbf{G}_m = (\mathbf{H}_m^H \mathbf{H}_m)^{-1} \cdot \mathbf{H}_m^H \tag{5}$$

with

$$\mathbf{G}_m = \begin{bmatrix} g_m^{(0,0)} & \cdots & g_m^{(0,N_r-1)} \\ \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot \\ g_m^{(N_t-1,0)} & \cdots & g_m^{(N_t-1,N_r-1)} \end{bmatrix}, \tag{6}$$

and

$$\mathbf{H}_m = \begin{bmatrix} h_m^{(0,0)} & \cdots & h_m^{(0,N_t-1)} \\ \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot \\ h_m^{(N_r-1,0)} & \cdots & h_m^{(N_r-1,N_t-1)} \end{bmatrix}. \tag{7}$$

III POWER ALLOCATION SCHEME

The proposed scheme is based on a simple procedure which consists of performing frequency domain optimization of the transmit power in function in term of the CSI and the expression of the approximated BER [5].

A *Bit Error Rate approximation*

Recently, it has been proposed in [6] and [7] that the heuristic expression to approximate the BER is obtained as:

$$f(\beta_{l,m}, p_{l,m}) \approx a \cdot \exp\left\{ - b \cdot \beta_{l,m} \cdot p_{l,m} \right\} \tag{8}$$

where $\beta_{l,m}$ is equal to:

$$\beta_{l,m} = \frac{1}{(2^{N_m} - 1).\sigma_n^2 . \sum_{n=0}^{N_r-1} |g_m^{(l,n)}|^2} \tag{9}$$

Table 1: Transmission modes for QPSK modulation

Modulation	QPSK	QPSK	QPSK
Coding Rate	1/2	3/4	1
Rate (bits/symb.)	1	1.5	2
a	7	16	0.2
b	9.5	5.4	1.66

Table 2: Transmission modes for 16-QAM modulation

Modulation	16-QAM	16-QAM	16-QAM
Coding Rate	1/2	3/4	1
Rate (bits/symb.)	2	3	4
a	4	14	0.2
b	11	6	1.73

where N_m is the number of bits per symbol($N_m = 2$ for QPSK, $N_m = 4$ for 16-QAM and $N_m = 6$ for 64-QAM) and $\beta_{l,m}$ denotes an equivalent received signal-to-noise ratio (SNR), which depends on the modulation scheme and the equalizer weights on the m-th subcarrier and l-th transmit antenna.

The parameters a and b are to be determined in a heuristic way, namely, via computer simulations. In this paper, we consider the following two MIMO-OFDM systems [7]:

-Uncoded OFDM: Without forward error correction (FEC) with QPSK and QAM modulations.

-Convolutionally coded OFDM: With the convolutional code in [8]. The generator polynomial of the mother code is $g = [133, 171]$. The coding rates are obtained from the puncturing pattern described in [8].

Tables 1, 2 and 3 respectively summarize the parameters of a and b for QPSK, 16-QAM and 64-QAM obtained via computer simulations. In the tables, the coding rate of 1 means the uncoded MIMO-OFDM system.

B *Proposed principle*

The basic principle of the proposed frequency domain power allocation for MIMO-OFDM signal is to combine spatial and frequency domains optimization of the transmit power in function of the channel state information (CSI) and the expression of the heuristic BER expression [5] defined in (8). 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 MIMO OFDM symbol which is represented by $(N \cdot N_t)$ 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

Table 3: Transmission modes for 64-QAM modulation

Modulation	64-QAM	64-QAM	64-QAM
Coding Rate	1/2	3/4	1
Rate (bits/symb.)	3	4.5	6
a	1.5	7	0.15
b	12	6	1.68

the allocation scheme N/N_s times.
Let first define the proposed transmit power matrix of the t-th subcarrier group as

$$\mathbf{p}_o^{'(t)} = \begin{bmatrix} p^{'}_{0,t\cdot N_s,\mathbf{o}} & \cdots & p^{'}_{0,(t+1)\cdot N_s-1,\mathbf{o}} \\ \cdot & \cdots & \cdot \\ \cdot & \cdots & \cdot \\ p^{'}_{N_t-1,t\cdot N_s,\mathbf{o}} & \cdots & p^{'}_{N_t-1,(t+1)\cdot N_s-1,\mathbf{o}} \end{bmatrix} \quad (10)$$

Then, we consider power distribution for the t-th subcarrier group under the condition that the average transmit power are kept constant to be $\overline{P}$. The optimization problem can be given by

$$\begin{cases} \mathbf{p_o}^{'(t)} = \arg\min \sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} \frac{f(\beta^{'}_{l,t\cdot N_s+m}, p^{'}_{l,t\cdot N_s+m})}{N_s\cdot N_t} \\ \text{s.t.} \sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} p^{'}_{l,t\cdot N_s+m} = N_s\cdot N_t\cdot \overline{P} \end{cases} \quad (11)$$

One possibility to solve this optimization problem is to apply the Lagrangian procedure. Defining:

$$J(\mathbf{p_o}^{'(t)}) = \sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} \frac{f(\beta_{l,t\cdot N_s+m}, p_{l,t\cdot N_s+m})}{N_t\cdot N_s} + \lambda\cdot(\sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} p_{l,t\cdot N_s+m} - N_t\cdot N_s\cdot\overline{P}), \quad (12)$$

The optimal solutions are obtained by solving for $0\le l < N_t$ and $0 \le m < N_s$:

$$\begin{cases} \frac{\partial}{\partial p_{l,m}}\left(\sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} \frac{f(\beta_{l,t\cdot N_s+m}, p_{l,t\cdot N_s+m})}{N_t\cdot N_s}\right) + \lambda = 0 \\ \sum_{l=0}^{N_t-1}\sum_{m=0}^{N_s-1} p_{l,t\cdot N_s+m} - N_t\cdot N_s\cdot\overline{P} = 0 \end{cases} \quad (13)$$

After calculation and rearrangement for $0\le l < N_t$ and $0 \le m < N_s$, we finally obtain:

$$p_{l,t\cdot N_s+m,\mathbf{o}} = \left[\sum_{u=0}^{N_t-1}\sum_{v=0}^{N_s-1}\frac{\beta_{l,t\cdot N_s+m}}{\beta_{u,t\cdot N_s+v}}\right]^{-1}\cdot\left[N_t\cdot N_s\cdot\overline{P} + \frac{1}{b}\cdot\sum_{u=0}^{N_t-1}\sum_{v=0}^{N_s-1}\frac{1}{\beta_{u,t\cdot N_s+v}}\cdot log\left(\frac{\beta_{l,t\cdot N_s+m}}{\beta_{u,t\cdot N_s+v}}\right)\right] \quad (14)$$

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: $p_{l,m} \le 0$. In this case we propose to apply the conventional scheme. We repeat the power allocation process for each subset of subcarriers and transmit antenna which compose the MIMO-OFDM symbol and each transmit antenna.

IV EXPERIMENTATION

We now evaluate the performance of the proposed power allocation method for MIMO-OFDM scheme in a mutli-path fading environment with ZF detection. We assume perfect knowledge of the channel variations both at the transmitting and receiving parts. An exponentially decaying (1-dB decay) multi-path model is assumed and carrier frequency is equal to 2.4GHz. The IFFT/FFT size is 64 points and the guard interval is set up at 16 samples [8].

Table 4: Simulation Parameters

Carrier Frequency	2.4 GHz
Bandwidth	20 MHz
(N_t, N_r)	(2,2), (4,4)
Modulations	QPSK, 16-QAM, 64-QAM
Channel encoder	No code and convolutional code
Coding gain	R=1/2, 3/4 and 1
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	40
Subgroup size (N_s)	2, 4, 8, 16, 32, 64

A Uncoded MIMO-OFDM

Effect of proposed scheme for several subset sizes is highlighted for the antenna configuration $N_t = N_r = 4$, without channel encoder R=1 for QPSK and QAM modulations.

Figs. 1, 2, and 3 show the BER versus the total received SNR (dB) of the proposed scheme with various subcarrier group sizes N_s. The BER performance of the conventional scheme (equal power distribution) is also plotted in the same figure.

The simulation results in Fig. 1 shows that, for QPSK modulation at average BER=10^{-4}, 2.8, 4.5, 5.2, 6.1, and 8.7 dB gains are respectively obtained for N_s= 2, 4, 8, 16 and 64.

Figs. 2 and 3 show the BER performance with 16-QAM and 64-QAM modulations, respectively for several subcarrier group sizes. From these figures, we can see that the proposed scheme can achieve significant performance gain also for QAM modulations.

It is shown that the subcarrier grouping size strongly affects the performance of the proposed scheme for both QPSK and

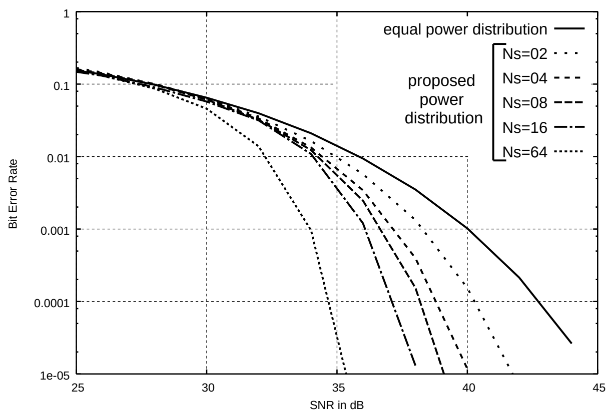

Figure 1: Bit error rate performance for QPSK modulation and coding rate R=1

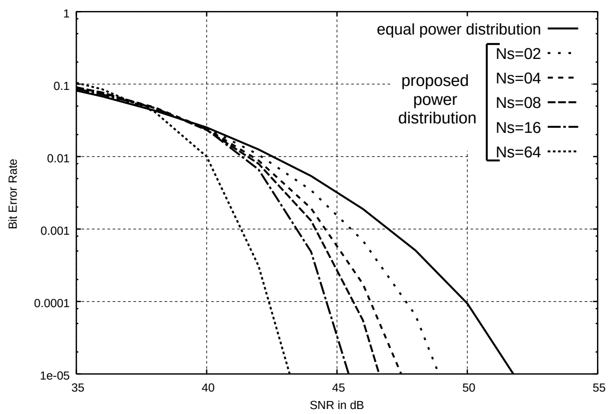

Figure 2: Bit error rate performance for 16-QAM modulation and coding rate R=1

QAM modulations. However, due to the structure of the proposed power distribution scheme, there is a trade-off between the subcarrier grouping size and the computational complexity.

B Coded MIMO-OFDM

In Figs. 4, 5, and 6, the benefit of performing the proposed scheme, in function of the total received SNR, is highlighted for the specific case of $R = 1/2$, $N_t = N_r = 4$, and QPSK and 64-QAM modulations. The simulation results show that at average BER=10^{-4}, between 2.5dB and 6dB gains are obtained depending on the subcarrier grouping size (N_s=2, 4, and 64) for QPSK modulation. In the case of 16-QAM and 64-QAM modulations, the proposed power allocation with ordering allows to obtain between 2.5 and 7dB gain depending on the size of the subcarrier grouping, N_s. The benefit in term of gain for QAM modulation is comparable to the QPSK modulation.

In Figs. 7 and 8, the benefit of performing the proposed power allocation scheme on coded MIMO OFDM system with $N_t = N_r = 2$, $R = 3/4$, QPSK and QAM modulations is presented. Results are presented for a wide range of subcarrier grouping size, N_s from 2 to 64. The simulation results

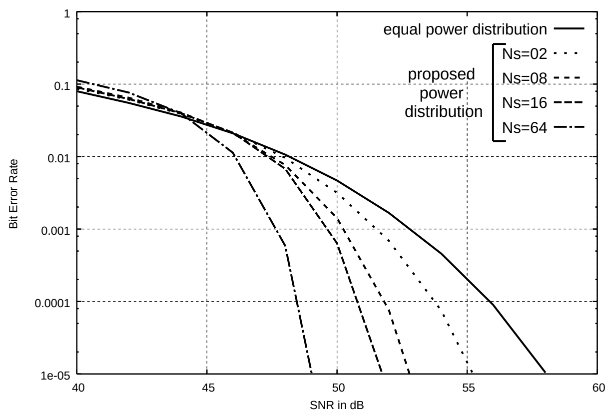

Figure 3: Bit error rate performance for 64-QAM modulation and coding rate R=1

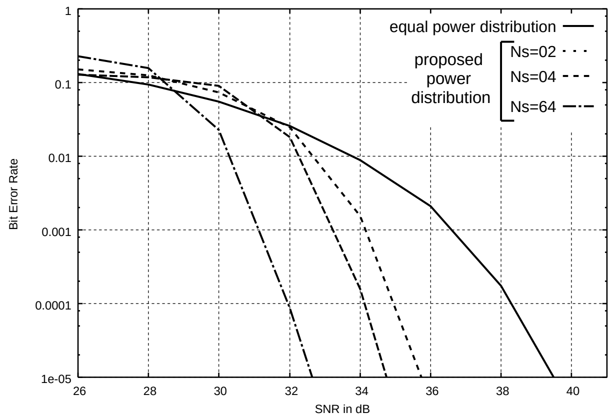

Figure 4: Bit error rate performance for QPSK modulation and coding rate R=1/2

show that at average BER=10^{-4}, significant gain are obtained by simply performing the proposed power distribution scheme. In the proposed scheme, the impact of the subcarrier group size strongly affects the BER performance. So the series of results, presented with computer simulations, highlight the fact that trade off between group size order and performance should be considered to define the most appropriate selection of the parameter N_s.

V CONCLUSION

This paper proposes a method for MIMO-OFDM that adapts the transmit power in both the spatial and the frequency domains using a heuristic expression of the BER for each subcarrier and transmit antenna. A closed form expression of the optimum power to be allocated for each subcarrier and transmit antenna has been presented for uncoded MIMO-OFDM transmission as well as coded scheme. Proposed scheme allows us to reduce the computational complexity, by simply including a subcarrier grouping method with local power adaptation in each subcarrier group. The simulation results show signifi-

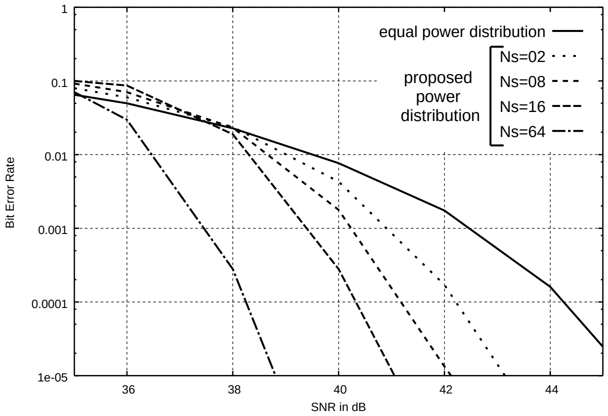

Figure 5: Bit error rate performance for 16-QAM modulation and coding rate R=1/2

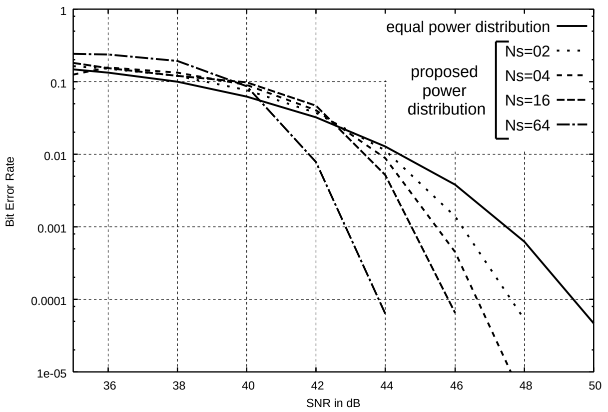

Figure 6: Bit error rate performance for 64-QAM modulation and coding rate R=1/2

cant improvement of BER performance both in the uncoded and coded cases for QPSK and QAM modulations compared to the equal power allocation scheme. Furthermore, combining the proposed scheme to any powerful detection such as V-BLAST or maximum likelihood detection (MLD) can be also implemented. In this paper, we have limited the channel coding scheme to the convolutional code, however, other powerful coding schemes such as the Turbo Codes (TC) or Low Density Parity Check (LDPC) can also be included in the modulated transmission. Finally, future orientation for this work would include the introduction of the error in the channel estimation.

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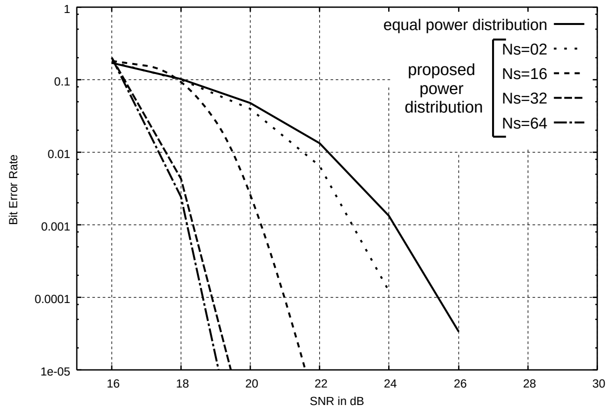

Figure 7: Bit error rate performance for QPSK modulation and coding rate R=3/4

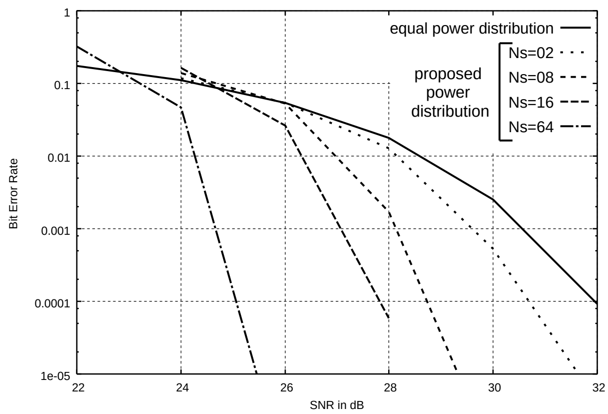

Figure 8: Bit error rate performance for 16-QAM modulation and coding rate R=3/4

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