COST 254

Emerging Techniques for Communication Terminals

French Chapter
Signal Processing

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07-09 July 1997

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Scientific Organization

The very fast increase of processing capabilities which are already (or will be hopefully soon) available on-board terminals, allow users and designers to look upon today's sophisticated algorithms as potential standard processings in near future terminals. Invited tutorials will offer a good coverage of the relevant subjects.

A large place will be reserved to presentations, either oral or poster, ranging from algorithms and methods to description of simulations, prototypes and systems. The topics selected for this workshop aim at giving a complete view of these classes of results, for the user side of the terminals, as well as for its network interface.

téléconférence stereophonique, A. Ben Rabaa - R. Tourki - Factulté des Sciences de Monastir

2.11 Test bench for a GSM mobile station of the newest generation, R. Passini - R. Bortoletti - F. Vatta - E. Valentinuzzi - Universita Degli Studi di Trieste

2.12 Network optimisation for remote multimedia imaging applications, U. Burnik - JF. Tasic - University of Ljubljana

2.13 An adaptive filtering technique for the LPC analysis/synthesis, M. Ionita - C. Burileanu - M. Ionita - University of Bucharest

2.14 Adaptive Kalman filter for speech enhancement from colored noise, Elimberaza Mandridake - ENSERB

2.15 Broadband multirate directional filters design principles with application to digital hearing aids, R. Golebiewski - A. Dabrowski - Poznan University of Technology

2.16 Digital TV - A flexible COFDM modem for digital terrestrial television broadcasting, E. Harborg - SINTEF

2.17 Image and video communication, E. Harborg - SINTEF

*** 15 h 00 - 17 h 00 - POSTER SESSION 2:** ***Digital Signal Processing and Communications***

3.1 Staircase algorithms for nonlinear equalization, Anibal R. Figueiras-Vidal - Universidad Carlos III de Madrid

3.2 Transmitter power control algortithms for cellular radio networks, Abbas Mohammed - S. Sali - University of Newcastle

X **3.3** Degradation of OFDM, OFDM and FDMA systmes caused by carrier phase jitter, Marc Moeneclaey - University of Ghent

3.4 Removal of length dependent local minima in CMA equalizers, Carlos J. Escudero - Luis Castedo - Universidad de la Coruna

3.5 A robust beamformer based on an iterative subspace projection with conjugate gradient techniques, Daniel Segovia Vargas - ETSI Telecommunication

3.6 Neural network identification of rapidly fading nonlinear channels, Mounir Ghogho - INPT

3.7 Multisensor-multiuser receiver for frequency selective CDMA channels, Juan Fernandez Rubio - Universitat Politecnica de Catalunya

3.8 Almost sure and quadratic mean convergence of adaptive filters in data transmission : finite alphabet approach, H. Besbes - M. Jaidane - J. Ezzine - L.S. TELECOMS

3.9 Superiority of the LMS over the RLS for tracking general markovian time-varying channel, H. Besbes - M. Jaidane - L.S. TELECOMS

3.10 Choice of an equalizer for a high rate date transmission system in an indoor radio channel, C. Faucheux - M. Joindot - TDF - C2R

3.11 A PSP based receiver for mobile communications, JE Hakegard - ML Boucheret - ENST

3.12 A step towards equalization for radiomobile channels : neural networks and variable selection, B. Dorizzi - JC. Mota - F. Albu - INT

3.13 Investigation of near-far problem for DS-CDMA systems, Abbas Mohammed - University of Newcastle

3.14 Digital communication using chaotic basis functions, MP. Kennedy - G. Kolumban - University College Dublin

3.15 Blind adaptive interference suppression for direct dequence CDMA, J. Miguez - C. Escudero - L. Castedo - Universidade da Coruna

3.16 Adaptive spectrum control in digital communications by predistortion, FJ. Gonzales-Serrano - A. Figueiras-Vidal - A. Artes-Rodriguez - ETSI Telecomunicacion

3.17 Evaluation of burst synchronization performance, J. D'Hollander - C. Bergogne - L. Roullet - Alcatel Espace

3.18 Combined Source-Channel Coding for Uniform Memoryless Sources, S. Zahir Azami - G. Feng - ENST

3.19 DTW algorithm with associated matrix for a passworded access system, M. Ionita - C. Burileanu - M. Ionita - University of Bucharest

3.20 Application of nonuniform discrete fourier transform to detection of DTMF signals, A. Dabrowski - T. Marciniak - Poznan University of Technology

*** 18 h 30 - RECEPTION** at the **CITY HALL** of **TOULOUSE**

Degradations of OFDMA, OFDM and FDMA systems caused by carrier phase jitter

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Abstract

In this contribution, we investigate the sensitivity to carrier phase jitter of an orthogonal frequency-division multiple access (OFDMA) system. We compute the degradation, caused by phase jitter, of the signal-to-noise ratio at the input of the decision device. When all OFDMA carriers have the same power level and the same jitter spectrum, this degradation is shown to be independent of the shape of the jitter spectrum, and to be equal to the degradation of an OFDM system. For the sake of comparison, we also consider the degradation of a traditional FDMA system. For a jitter bandwidth much smaller than the symbol rate, the degradation for FDMA is the same as for OFDMA. When the jitter bandwidth increases, FDMA is found to be slightly more robust than OFDMA.

I. Introduction

Orthogonal frequency-division multiple access (OFDMA) is closely related to orthogonal frequency-division multiplexing (OFDM), which is well documented in the literature (e.g. [1-3]).
In the case of OFDM, a user's data stream to be transmitted is split into a large number of lower rate data streams, which each modulate a different sinusoidal carrier. The modulated carriers are orthogonal by making the carrier spacing equal to the symbol rate per carrier, and by aligning in time the data symbols on the different carriers. The data symbols are recovered by performing a fast Fourier transform (FFT) on the received signal samples.
In the case of OFDMA, the received signal can be viewed as an OFDM signal, but with each carrier generated by a different user instead of all carriers generated by the same user. Because of the relation between the carrier spacing and the symbol rate per carrier, the modulated carriers of the OFDMA signal are spectrally overlapping. Hence, OFDMA is more bandwidth efficient than traditional FDMA, where the modulated carriers occupy nonoverlapping frequency bands. In addition, when the receiver has to demodulate all user signals, OFDMA is more advantageous than traditional FDMA, because an FFT is less complex to implement than a bank of filters. In [4], OFDMA has been proposed as access technique for the return channel in a CATV network, i.e. for the communication from the users to the headend.
In an OFDMA scenario, the receiving station (e.g. the headend in a CATV network) transmits network synchronization signals to the different users, from which these derive the appropriate carrier frequency, symbol rate and time alignment, needed for the orthogonality of the modulated carriers. For instance, each user generates its sinusoidal carrier from the received synchronization signals by means of a phase-locked loop (PLL).
In this paper we consider the case where the sinusoidal carriers from the different users are affected by phase jitter, occurring in the PLL systems that generate these carriers. We show that the phase jitter gives rise to intercarrier interference at the receiver, so that the signal-to-noise ratio (SNR) at the input of the decision device is reduced. We present an expression for the degradation of the SNR, in terms of the power levels and phase jitter spectra of the different users.

II. System description

The complex envelope r(t) of the received OFDMA signal is given by

$$r(t)=\sum_{m}\sum_{\ell=0}^{N-1}\sum_{n=0}^{N-1} s_{m,\ell,n}\,p(t-(mN+\ell)\tfrac{T}{N})\exp(j\varphi_n(t))+N(t)$$

$$s_{m,\ell,n}=a_{m,n}\sqrt{\tfrac{E_{s,n}}{N}}\exp\left(j2\pi\tfrac{n\ell}{N}\right) \qquad (1)$$

where $a_{m,n}$ denotes the *m*th data symbol (with unit energy) transmitted by the *n*th user on the carrier with frequency n/T, N is the number of orthogonal carriers, 1/T is the symbol rate per carrier, and N/T is the total symbol rate. Data symbols generated by different users are uncorrelated. The pulse p(t) is a real-valued unit energy square-root Nyquist pulse with respect to the interval T/N. $E_{s,n}$ denotes the energy per symbol for the *n*th user, and N(t) represents the additive noise. In a CATV environment this additive noise consists of ingress noise [5], which is characterized by a strongly frequency-dependent power spectral density (psd). The process $\varphi_n(t)$ denotes the phase jitter from the *n*th user, and is modeled as a stationary zero-mean process whose bandwidth is much smaller than N/T. The phase jitter processes related to different users are uncorrelated for OFDMA. In order to detect the symbol $a_{k,n}$, the receiver feeds to the decision device the quantity $z_n(kT)$, which is obtained by evaluating at the frequency n/T the discrete Fourier transform of the matched filter output samples taken at the instants $(kN+\ell)T/N$ with ℓ = 0, ..., N-1. The matched filter has impulse response p(-t).

III. Carrier phase jitter

In this section, we compute the degradation (in dB) of the signal-to-noise ratio (SNR) at the input of the decision device when carrier phase jitter is present.

Let us concentrate on the detection of the symbol $a_{0,n}$. The variation of the phase jitter over the impulse response duration of the matched filter (which is in the order of T/N) can be neglected, because of the small bandwidth of the jitter. The input to the decision device is given by

$$z_n(0)=\sqrt{E_{s,n}}\,a_{0,n}I_{n,0}+\sum_{\substack{m=0\\ m\neq n}}^{N-1}\sqrt{E_{s,m}}\,a_{0,m}I_{m,n-m}+W_n(0) \qquad (2)$$

where

$$I_{m,k}=\frac{1}{N}\sum_{\ell=0}^{N-1}\exp\left(j\varphi_m(\tfrac{\ell T}{N})\right)\exp(-j2\pi\tfrac{k\ell}{N}) \qquad (3)$$

and $W_n(0)$ denotes the noise term. The quantity $I_{m,k}$ is the discrete Fourier transform of $\{\exp(j\varphi_m(\ell T)) \mid \ell=0, \ldots, N-1\}$, evaluated at the frequency k/T. Note that for $\varphi_m(t) = 0$, we obtain $I_{m,0} = 1$ and $I_{m,k} = 0$ for $k\neq 0$. The second term in (2) is intercarrier interference (ICI). The first term in (2) can be decomposed into a useful component, equal to $a_{0,n}E[I_{n,0}]$, and a zero-mean fluctuation about the useful component.

The phase jitter $\varphi_m(t)$ contributes to the disturbance in (2) through the term $\sqrt{E_{s,m}}\,a_{0,m}I_{m,n-m}$ when $m\neq n$ or the term $\sqrt{E_{s,n}}\,a_{0,n}\left(I_{n,0}-E[I_{n,0}]\right)$ when m=n. As each of these contributions contains a different data symbol, the contributions are uncorrelated. Consequently, the variance of the total disturbance in (2), caused by phase jitter, equals the sum of the variances of these individual contributions.

Using in (3) the approximation $\exp(j\varphi_m(\ell T/N)) \cong 1 + j\varphi_m(\ell T/N)$, we obtain for $k\neq 0$,

$$I_{m,k}\cong\frac{1}{N}\sum_{\ell=0}^{N-1} j\varphi_m(\tfrac{\ell T}{N})\exp(-j2\pi\tfrac{k\ell}{N})$$

Similarly,

$$I_{n,0}\cong 1+\frac{1}{N}\sum_{\ell=0}^{N-1} j\varphi_n(\tfrac{\ell T}{N})$$

Hence, the components of $\varphi_i(t)$ near the frequency k/T affect the detection of the data symbols from the *(i+k)*th user.

In the absence of phase jitter, the signal-to-noise ratio (SNR) at the input of the decision device corresponding to the *n*th user equals $E_{s,n}/E[|W_n(0)|^2]$. In the presence of phase jitter, the SNR is reduced. This degradation, expressed in dB, is given by

$$D_n=10\log\left(\begin{aligned}&1+\frac{E_{s,n}}{E\left[|W_n(0)|^2\right]}E\left[\left|I_{n,0}-E[I_{n,0}]\right|^2\right]\\&+\sum_{\substack{m=0\\ m\neq n}}^{N-1}\frac{E_{s,m}}{E\left[|W_n(0)|^2\right]}E\left[\left|I_{m,n-k}\right|^2\right]\end{aligned}\right) \qquad (4)$$

In the following we consider the degradation (4) under the assumption that the energy per symbol and the jitter spectrum equal E_s and $S_\varphi(\exp(j2\pi fT))$, respectively, for all N users. In this case, the degradation (4) reduces to

$$D_n = 10\log\left(1 + \frac{E_s\sigma_\varphi^2}{E\left[\left|W_n(0)\right|^2\right]}\right) \quad (5)$$

where σ_φ^2 is the jitter variance. Hence, when the signals received by the different users have the same energy per symbol and the same jitter spectrum, the degradation depends on the jitter variance, but not on the specific shape of the jitter spectrum.

IV. Comparison with OFDM

In the case of OFDM, the received signal is again given by (1), but with $E_{s,n}=E_s$ and $\varphi_n(t)=\varphi(t)$ for n = 0, …, N-1 : the power level of all carriers is the same, and all carriers exhibit identical phase jitter as they are generated by the same oscillator. Following the same reasoning as in section III, we obtain that the degradation of the SNR is given by (5). This is in agreement with the result from [6], where the degradation for OFDM has been computed assuming an AWGN channel.

It might be surprising that OFDMA (with *uncorrelated* phase noise processes having the same psd $S_\varphi(\exp(j2\pi fT/N))$) and OFDM (where all carriers exhibit *identical* phase jitter with psd $S_\varphi(\exp(j2\pi fT/N))$) yield the same degradation (5) of the SNR. However, as the individual contributions to the disturbance in (2) are uncorrelated when the data symbols are uncorrelated, the degradation of the SNR is not affected by the presence or absence of correlation between the phase jitter processes.

V. Traditional FDMA

In the case of traditional FDMA, the modulated carriers occupy nonoverlapping frequency bands. As far as the detection of the data symbols from the *n*th user is concerned, the complex envelope of the received signal is given by

$$r(t) = \sqrt{E_{s,n}}\sum_m a_{m,n}\tilde{p}(t-mT)\exp(j\varphi_n(t)) + N(t)$$

where $\tilde{p}(t)$ is a real-valued square-root Nyquist pulse with respect to the interval T, and the other quantities have the same meaning as in (1). In order to detect the symbol $a_{k,n}$, the receiver feeds to the decision device the quantity $z_n(kT)$, which is obtained by sampling at the instant kT the output of the matched filter (with impulse response $\tilde{p}(-t)$) which is driven by r(t).

Let us concentrate on the detection of the symbol $a_{0,n}$. The sample $z_n(0)$ is given by

$$z_n(0) = \sqrt{E_{s,n}}\,a_{0,n}\tilde{I}_{n,0} + \sqrt{E_{s,n}}\sum_{m\neq 0} a_{m,n}\tilde{I}_{n,m} + W_n(0) \quad (6)$$

where

$$\tilde{I}_{n,m} = \int_{-\infty}^{+\infty}\exp(j\varphi_n(t))\tilde{p}(t)\tilde{p}(t-mT)\,dt$$

and $W_n(0)$ denotes additive noise.

In the case where $\varphi_n(t)$ is essentially constant over the duration of $\tilde{p}(t)$ (which is in the order of T), we obtain

$$\tilde{I}_{n,m} \cong \begin{cases}\exp(j\varphi_n(0)) & m=0\\ 0 & m\neq 0\end{cases} \quad (7)$$

Hence, the intersymbol interference (ISI) term (i.e. the second term in (6)) is caused solely by the fluctuation of the phase jitter over the duration of $\tilde{p}(t)$.

Using the approximation $\exp(j\varphi_n(t)) \cong 1 + j\varphi_n(t)$ yields

$$\tilde{I}_{n,0} \cong 1 + j\int_{-\infty}^{+\infty}\varphi_n(t)\tilde{p}^2(t)\,dt$$

and, for m≠0,

$$\tilde{I}_{n,m} \cong j\int_{-\infty}^{+\infty}\varphi_n(t)\tilde{p}(t)\tilde{p}(t-mT)\,dt$$

When the bandwidth of the phase noise is much smaller than 1/T, so that (7) is a valid approximation, the degradation for FDMA reduces to (5), in which case OFDMA and traditional FDMA suffer the same degradation.

VI. Numerical results

Fig. 1 shows the degradation D_n from (5) as a function of $E_{s,n}/[|W_n(0)|^2]$, for different values of the phase jitter variance $\sigma_{\varphi_n}^2$. For degradations less than about 1 dB, D_n is essentially proportional to $E_{s,n}/[|W_n(0)|^2]$ and $\sigma_{\varphi_n}^2$. The degradation (5) holds for both OFDMA and OFDM, provided that all carriers have the same power level and the same jitter spectrum.

Now we compare the degradations for OFDMA and traditional FDMA, respectively. We have assumed that $\tilde{p}(t)$ is a square-root cosine rolloff pulse, and the jitter psd is given by

$$S_{\varphi_n}(f) = \begin{cases} \sigma_{\varphi_n}^2 \dfrac{1}{B}\left(1-\dfrac{|f|}{B}\right) & |f| < B \\ 0 & |f| \geq B \end{cases}$$

with B denoting the jitter bandwidth. For $\sigma_{\varphi_n}^2 = 10^{-4}$ and $E_{s,n}/E[|W_n(0)|^2] = 25$ dB, Fig. 2 shows the degradations as a function of the jitter bandwidth B, normalized to the symbol rate 1/T. For OFDMA, the degradation does not depend on the shape of the jitter spectrum. For FDMA, the degradation decreases with increasing jitter bandwidth and with decreasing rolloff. When the jitter bandwidth is much smaller than the symbol rate, the approximation (7) holds, in which case the degradation for FDMA converges to the degradation for OFDMA. When the jitter bandwidth is less than the symbol rate, we observe that FDMA is only slightly more robust against phase jitter than OFDMA.

VII. Conclusions and remarks

In this paper, we have investigated the degradation, caused by carrier phase jitter, of the signal-to-noise ratio (SNR) at the input of the decision device, for OFDMA, OFDM and traditional FDMA. Our results can be summarized as follows :

- Assuming that all carriers have the same power level and the same jitter spectrum, the degradation for OFDMA depends on the jitter variance but not of the shape of the jitter spectrum. The degradation, expressed in dB, is essentially proportional to the jitter variance and to $E_{s,n}/[|W_n(0)|^2]$.
- The degradation for OFDMA is not affected by the correlation between the phase jitter processes on different carriers. As OFDM can be considered as OFDMA with identical phase jitter on the different carriers, the degradation for OFDM is the same as for OFDMA with the same jitter spectrum on all carriers.
- The degradation for traditional FDMA depends on the shape of the jitter spectrum. When the jitter bandwidth is much smaller than the symbol rate, the degradation for FDMA is essentially the same as for OFDMA. When the jitter bandwidth increases, the degradation for FDMA decreases. When the jitter bandwidth does not exceed the symbol rate, the degradation for FDMA is only slightly less than the degradation for OFDMA.

We have restricted our attention to the case of a nondispersive channel, and have assumed perfect timing alignment between the different users in the OFDMA scenario. Dispersive channels and alignment errors can be dealt with by introducing at the transmitter a guard interval containing a cyclic prefix [1-4]. The presented results for OFDMA can be extended to this case by simply replacing in (4) $E_{s,m}$ by $NE_{s,m}|H_m(m/T)|^2/(N+\nu)$, where $H_m(f)$ is the channel transfer function for the *m*th user, and the guard interval duration equals $\nu T/N$.

References

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3. Chow, J.-C. Tu and J.M. Cioffi, "A discrete multitone transceiver for HDSL applications," IEEE J. Select. Areas Commun., vol. SAC-9, pp. 895-908, Aug. 1991
4. Sari, Y. Lévy and G. Karam, "Orthogonal frequency-division multiple access for the return channel on CATV networks," Proc. International Conference on Telecommunications ICT'96, Istanbul, pp. 602-607, April 1996
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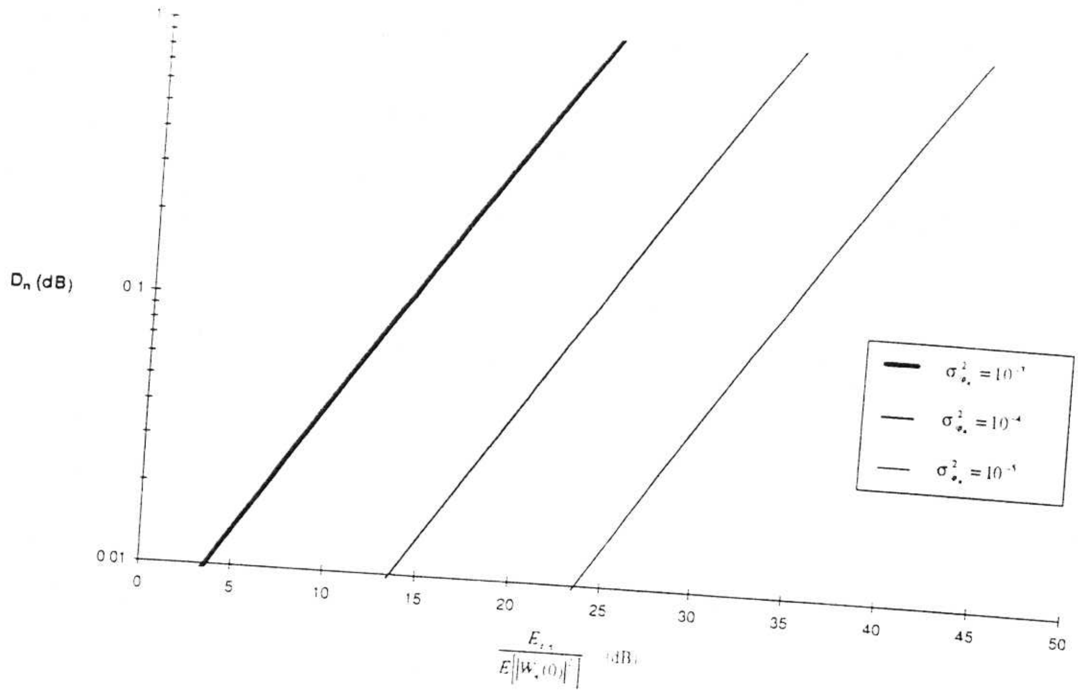

Fig. 1 : Degradation for OFDMA

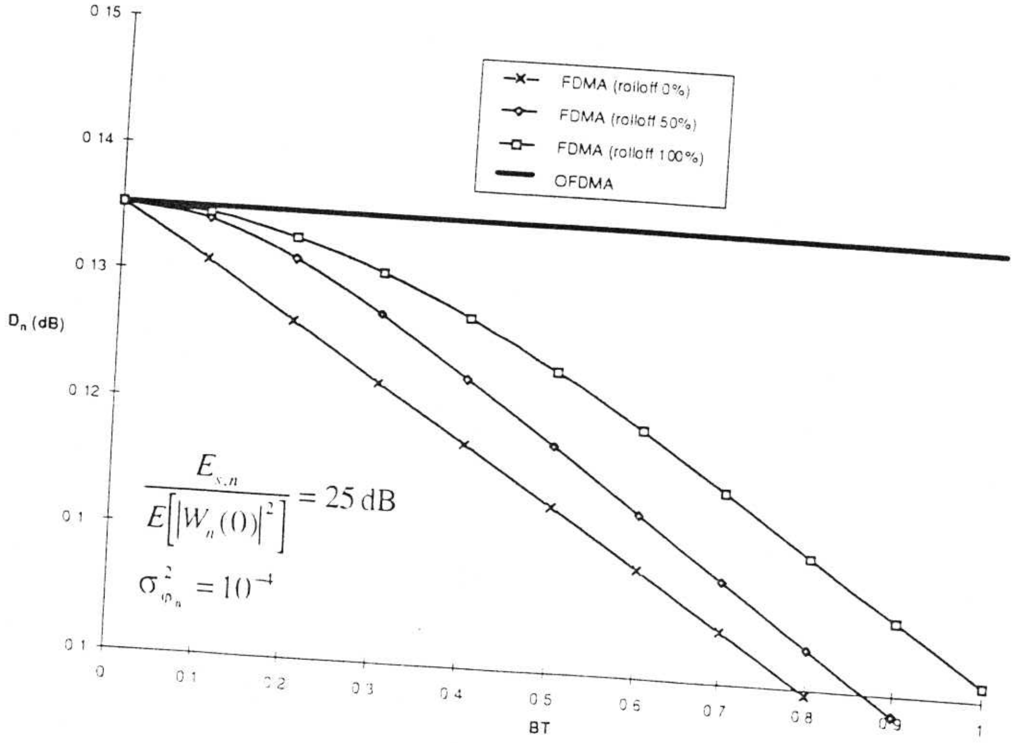

Fig. 2 : Comparison of degradations for OFDMA and FDMA