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Mohd Israil
Department of Physics, Swami Vivekanand Subharti University, Meerut, India

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ORIGINAL STUDY

Detection of Data Over Wireless Mobile Channels Based on Maximum Likelihood Technique

Mohd Israil

Department of Physics, Swami Vivekanand Subharti University, Meerut, India

Abstract

Next generation wireless systems are characterized by very high transmission bit rates which gives rise to severe Intersymbol interference (ISI) and this makes the detection process very challenging. Hence, assessment of performance of near-optimal detectors like Near Maximum Likelihood Detectors (NMLD) over such channels assumes great importance. This paper deals with the detection of data in the presence of Noise and ISI with NMLD. Performance improvement of NMLD, as compared to nonlinear equalization, has been assessed in terms of BER versus SNR curves obtained through computer simulation. A number of different cases of mobile radio channels have been simulated in this work. In current world the lot of congestion leads severe fading and interference in the channel which may give the pause in data streaming and call drop in voice calling. These channels have different number of reflected paths with different power distribution in the respective paths. The aim of this paper is to take a 'worst case' model of a mobile radio channel in terms of rapidity of fading and ISI, and then to investigate the performance of detectors in the receivers.

Keywords: Doppler spread, Equalization, ISI, Multipath fading and NMLD, MLD

1. Introduction

Wireless communications and electronics have advanced significantly in recent years [1,3] leads lot of challenges in the communications systems. Multipath propagation is an inherent feature of mobile radio communications and it arises because of the reflection and scattering of transmitted radio signals from buildings and other obstacles along the path. Due to the multipath propagation in a channel, the transmission of a very narrow pulse results in the reception of a train of pulses (or equivalently broadening of the pulse). The time difference between the reception of the first and the last of these received pulses is known as the multipath delay spread or time delay spread of the channel. When the multipath delay spread becomes large, the adjacent signal elements may interfere with each other. This leads to the presence of intersymbol interference (ISI) in the received signal [1,2], which in turn gives rise to degradation in the system performance. The ISI becomes serious when the multipath spread is approximately 40% or more of the duration of the signal element [3].

In order to accommodate new multimedia and Internet application services involving the transmission of text, audio and images over wideband mobile systems such as those that are going to be used in next generation wireless systems, the transmission bit rate over such mobile channels becomes extremely high. In this case, the time delay spread of the channel becomes appreciably large compared to the signal element duration. Such a model gives rise to a frequency selective fading channel wherein the received signal contains an appreciable degree of inter-symbol interference.

A technique to employ the baseband equivalent form of the bandpass channel on the modulated carrier signal fed through this channel. The modulator transmission path and the demodulator can now be modeled as linear baseband channel where all the filters at the transmission path are represented by the corresponding low pass filter and similarly at the receiver side. QAM Modulation is useful in 5G requirement for the modulation [3]. In this article the 4-QAM is used as the modulation part. The 4 QAM signal which is fed to the linear baseband channel is generated as separate in phase

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E-mail address: israilsaifi@gmail.com.

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and quadrature phase components. An important assumption made here is that the detectors have the perfect knowledge of the channel. This assumption is made because the objective of this work is to assess the performance of the detector. MATLAB is very attractive tool for the simulation of communication system [4], here in this article author used MATLAB tools for the generation data and channels with required parameters. This article is divided in five segments including first section of introduction, in section 2, wireless channels is simulated which followed by the major section of this paper i.e. detection in section 3 which is also simulation based with some fixed parameters and detector performance is recorded in terms of BER and SNR which has been discussed in section 4. In section 5 conclusion of the research is provided.

2. Channel modelling

In analog Frequency modulation, ‘wideband’ describes a situation when the modulation bandwidth is considerably larger than the bandwidth of the modulating signal. In RF engineering, the ‘wideband’ condition is encountered when – the ratio of bandwidth of a certain quantity (e.g. antenna bandwidth) compared to the carrier frequency – is much smaller than unity [5–7]. In digital mobile radio, which is the focus of this paper, the wideband system is described as the system whose time delay spread (τ_{sp}) is higher than the duration of the digital symbol (T_s). On the other hand, the system is defined as narrowband if it is true otherwise, i.e. if the time delay spread is much smaller than the duration of the digital symbol [7,8].

In digital mobile radio, which is the focus of this paper, the wideband system is described as the system whose time delay spread (τ_{sp}) is higher than the duration of the digital symbol (T_s). On the other hand, the system is defined as narrowband if it is true otherwise, i.e. if the time delay spread is much smaller than the duration of the digital symbol [9,10].

$\tau_{sp} > T_s$ (Wideband System)

$\tau_{sp} << T_s$ (Narrowband System)

The channel model is illustrated in Fig. 1 where the input signal is fed to a tapped delay line. A delay-line tap extracts a signal output from somewhere within the delay line, optionally scales it, and usually sums with other taps for form an output signal. Depending upon the variety of terrain including built-up urban and suburban/rural areas, the channel may have several significant resolvable paths with independent fading. The amplitude of these resolvable paths is Rayleigh distributed and the phase is uniformly distributed [11]. This paper addresses such ‘worst case’ models of mobile channels. The idea is that if a receiver can be designed to have a good tolerance to such a worst case design of a channel, then it is unlikely to have a poor performance over any practical channel that may be encountered in a mobile [9].

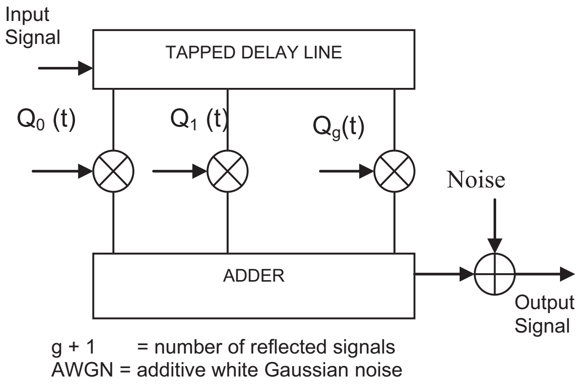

Fig. 1. Tapped Delay line model for generating Multipath channel.

The number of taps is equal to the number of the reflected signal reaching to the receiver via different fading paths. Output of the signal would be distorted, noisy and with intersymbol interference. Each of the Rayleigh fading paths is generated simply from two Gaussian noise sources $q_1(t)$ and $q_2(t)$. Each q_1 (t) and q_2 (t) are two statistically independent real-valued [7], Gaussian random waveforms, each with zero mean and the same power spectral density, q_1 (t) and q_2 (t) are generated independently by passing Gaussian noise source from two separate but identical filter. In this works five pole Bessel filter is used [12,13].

3. NML detection

In this paper two types of detection techniques employed for the detection of the faded noisy signal. The problem of dealing with ISI in the received signal has traditionally been overcome by equalizing the received signal before passing it on to the detector, but the performance of such a system is known to be very much sub-optimal [13,14]. On the other hand, the optimum detection process for a sequence of statistically independent data symbols transmitted over a non-ideal band-limited channel that introduces ISI and AWGN is maximum likelihood detection (MLD) [15]. MLD can be effectively implemented by Viterbi algorithm. However, the Viterbi detector generally suffers from the problem of excessive storage requirements and high computational complexity [16–19]. The general

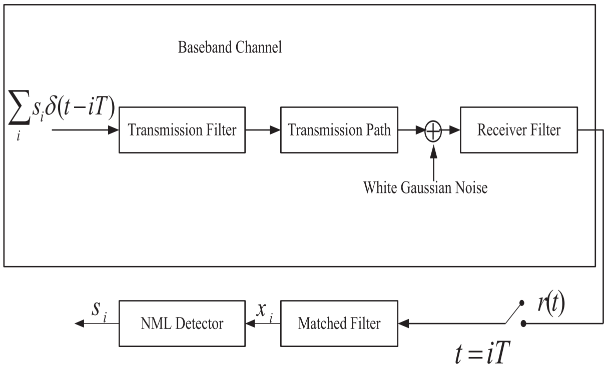

Fig. 2. Model for the transmission and detection process.

model for the transmission and reception is shown in Fig. 2.

3.1. Equalization

Equalization compensates the intersymbol interference (ISI) created by the multipath within time dispersive channel. Equalization must be adaptive in mobile environments, since the channel is generally unknown and time varying [9,11]. In this section, only nonlinear equalization techniques employed for detection process.

Non-linear equalization is one in which the detector is used within the feedback path as shown in Fig. 3. Since the detector is a highly nonlinear device, therefore equalization becomes nonlinear. Non-linear equalizer uses decision directed cancellation of inter-symbol interference (ISI). The received sample value at the input to the multiplier in Fig. 3, at time t = iT, is

$$r_i = s_i\ y_{i,0} + \sum_{j=1}^{g} s_{i-j}\, y_{i,j} + w_i \qquad (1)$$

The corresponding sample value at the output of the multiplier is

$$r_i \Big/ y_{i,0} = s_i + \sum_{j=1}^{g} s_{i-j}\left(y_{i,j} \Big/ y_{i,0}\right) + \left(w_i \Big/ y_{i,0}\right)$$

$$r_i \Big/ y_{i,0} = s_i + \sum_{j=1}^{g} s_{i-j} v_j + w_i \Big/ y_{i,0} \qquad (2)$$

where: $v_j = y_{i,j}/y_{i,0}$
Si = symbol to be detected
$w_i/y_{i,0}$ = noise component

$\sum_{j=1}^{g} S_{i-j} v_j$ = intersymbol interference

The sampled impulse-response of the baseband channel, sampler and multiplier is

$$1/y_{i,0}\ V = 1\ v_1\ v_2 \ldots \ldots v_g \qquad (3)$$

Assuming that $1/y_{i,0}\ V$ and the two possible initial values of s_i are known at the receiver, the output signal from the linear feed forward transversal filter in Fig. 3 is

$\sum_{j=1}^{g} s_{i-j}'\ vj$, where s_{i-j}' is the detected value of s_{i-j}.

Thus, the signal at the detector input at t = iT is

$$x_i = r_i \Big/ y_{i,0} - \sum_{j=1}^{g} s_{i-j}'\ v_j \qquad (4)$$

$$= s_i + \sum_{j=1}^{g} s_{i-j}\ v_j + = w_i \Big/ y_{i,0} - \sum_{j=1}^{g} s_{i-j}'\ v_j \qquad (5)$$

And with the correct detection of each si-j, such that

$s_{i\text{-}j}' = s_{i\text{-}j}$ for j = 1,2, ….g, then equation (5) becomes

$$x_i = s_i + w_i/y_{i,0} \qquad (6)$$

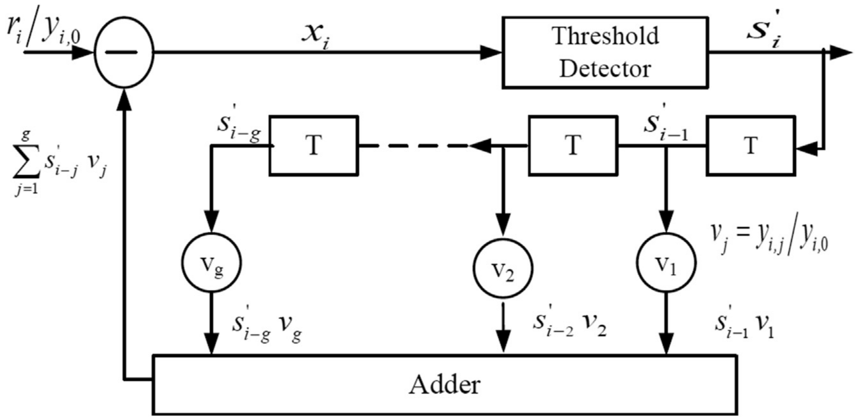

Fig. 3. Nonlinear equalizer.

3.2. Near maximum likelihood detection

Near-maximum likelihood (NML) detectors are a class of detectors that reduce this problem to a certain degree and are therefore investigated in this paper. The paper presents a performance analysis of the NML detectors over a number of mobile channels simulated in this work.

One method of reducing the complexity of the Viterbi detector when it involves large amount of components in the channel sampled impulse response (SIR), is to reduce the number of its stored vectors i.e. the number of its survivors. So instead of holdings m^g survivors, the detector may hold m' survivors where $m' < m^g$ and these are chosen according to some criterion. Here m represents the number of levels in the transmitted signal, and the channel sampled impulse response is assumed to consist of $g+1$ components. The criterion for the selection of m' vector ensures that the degradation in the tolerance to noise is kept to a minimum. The performance degradation relative to the optimum detector is dependent on the ratio of m'/m^g.

NML detectors are a derivative of Viterbi detectors where m' is much smaller than m^g and where all the m' stored vectors need not be survivors [19].

For near optimum performance of the NML detector, the magnitude of the first few components of the channel SIR should be large relative to other components. If the first component is the largest, the SIR is referred to as a minimum phase response. If the channel SIR is not a minimum phase (or near minimum phase), then some sort of processing ahead of the detector may be used to make the channel SIR as a minimum phase [20]. This is generally implemented by making use of an adaptive filter ahead of the detector. In the work presented in this paper, however, no adaptive prefiltering is used in order to reduce the overall complexity of the system. Since the channel used in this work is not a minimum phase (in fact it can be near maximum phase at times due to its very nature), the design of the detection algorithms becomes extremely challenging.

One important assumption assumed throughout the simulation is that the detectors have a ‘perfect knowledge’ (perfect estimation) of the channel at every time instant. The justification for making such assumption is that the objective of this work is to access the performance of NML detector in mitigating the signal fading over such channels. As such, the estimation techniques are therefore not studied in this paper.

The received signal sample is given by

$$r_i = \sum_{h=0}^{g} s_{i-h} y_{i,h} + w_i \tag{7}$$

where $\{s_i\}$ represents statistically independent data symbols, $\{y_{i,h}\}$ represents the channel SIR and $\{w_i\}$ represents statistically independent AWGN.

Just prior to the receipt of the signal sample r_i, the detector holds in store k different n−component vectors (sequences) $\{Q_{i-1}\}$, where

$$Q_{i-1} = [x_{i-n}\, x_{i-n+1} \ldots x_{i-1}] \tag{8}$$

and x_{i-h} can take any of the four possible values of s_{i-h} where $h = 1, 2, 3, \ldots, n$. Each vector Q_{i-1} represents a possible sequence of values of the data symbols $s_{i-n}, s_{i-n+1}, \ldots, s_{i-1}$. Also, each vector Q_{i-1} is formed by the last $(i-1)$−component vector X_{i-1} as shown in Fig. 4, where

$$X_{i-1} = [x_1\, x_2\, x_3 \ldots x_{i-1}] \tag{9}$$

and has associated with it the cost

$$U_{i-1} = \sum_{j=1}^{i-1} \left| r_j - \sum_{h=0}^{g} x_{j-h}\, y_{j,h} \right|^2 \tag{10}$$

where $x_i = 0$ for $i \leq 0$ and $|u|$ is the absolute value of the scalar quantity u. U_{i-1} is also taken to be the cost of the corresponding vector Q_{i-1}. It can be easily seen that the vector X_{i-1} most likely to be correct is that which has the smallest cost U_{i-1} over all combinations of possible values of the $\{x_j\}$.

On receipt of the sample r_i, each of the k-vectors $\{Q_{i-1}\}$ is expanded into m number of *(n + 1)* component vectors $\{P_i\}$ as shown in Fig. 5 where,

$$P_i = [x_{i-n}\, x_{i-n+1} \ldots x_{i-1}\, x_i] \tag{11}$$

In each group of m vectors $\{P_i\}$, derived from any one vector $\{Q_{i-1}\}$, the first n−components are as original Q_{i-1} and the last component x_i takes on its m possible values given the m possible values of s_i. In this work, $m = 4$ has been used. With each of these resulting vectors is associated its cost U_i given by

$$U_i = U_{i-1} + \left| r_i - \sum_{h=0}^{g} x_{i-h}\, y_{i,h} \right|^2 \tag{12}$$

where U_{i-1} is the cost of the vector Q_{i-1} from which P_i is derived.

The vector with the smallest cost U_i is now selected from the resulting set of 4k expanded vectors $\{P_i\}$. The detected value s'_{i-n} of the data symbol s_{i-n} is taken as the value of x_{i-n} in the selected vector. Any vector P_i whose first component x_{i-n}

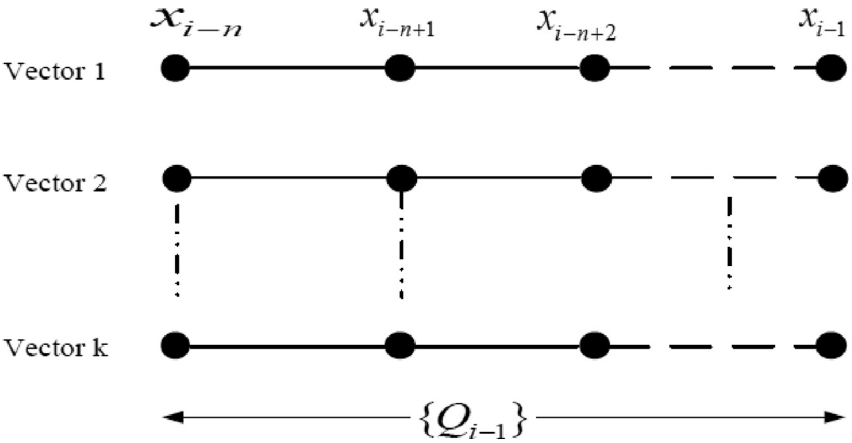

Fig. 4. No. of stored vector as shown in equation 9.

differs from s'_{i-n} is then discarded by assigning to it an arbitrarily high value of cost. From the remaining vectors $\{P_i\}$, including that from which s_{i-n} was detected, are selected the k vectors with the smallest costs $\{U_i\}$. The first component x_{i-n} of each of these k selected vectors $\{P_i\}$ is now omitted without altering their cost U_i. The discarding of the vectors just mentioned is a convenient method of ensuring that the k-stored vectors $\{Q_{i-1}\}$ are always different, provided only that they were different at the first detection process which can easily be arranged. These k-selected vectors $\{Q_i\}$ are now stored along with their associated costs $\{U_i\}$, where these costs are the same as those of $\{P_i\}$ from which $\{Q_i\}$ were derived. The smallest of these costs is now subtracted form each of the k costs, so that the smallest cost becomes zero. This is done in order to avoid an unacceptable increase in the value of the costs over a long message, and it does not change the differences between the costs. These k selected vectors $\{Q_i\}$ are then stored along with their costs $\{U_i\}$, and the detector is now ready for the next step of detecting s_{i-n+1} on the receipt of r_{i+1}. This process will continue till the last symbol.

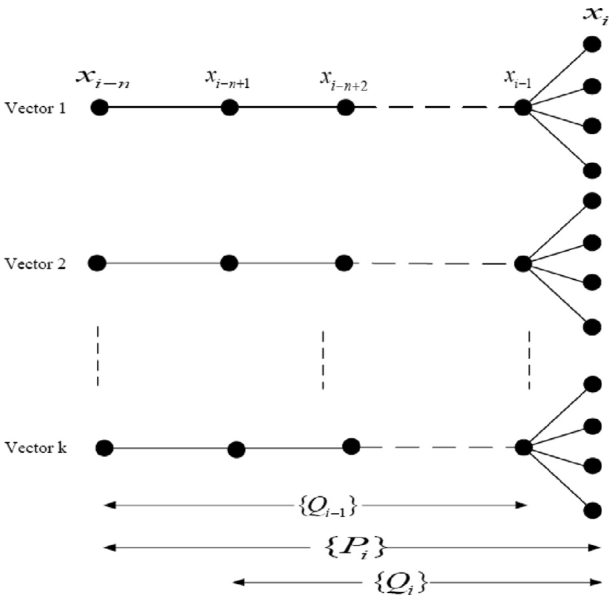

Fig. 5. NML detection system.

In the computer simulation tests, the number of stored vectors k in NMLD used is 4. The length of the stored vectors (delay in detection) represented by n is 4.

4. Result and discussions

This paper is considering three different cases of mobile radio fading channels with various power delay profiles and number of paths introduced in the channel. In this paper single path, two paths with equal power as well as unequal power distribution and three paths with equal power and unequal power distribution are considered. The carrier frequency used in this paper is 1.8 GHz and Doppler spread is 6 Hz, which is quite typical of indoor mobile radio channels.

CH21 is a two path frequency selective worst case fading channel with equal power distribution (amount of the ISI present in the signal is equal to the signal power), CH22 is two paths fading channel with power distribution [80% 20%]. CH24 is three paths fading channel with equal power distribution [33% 33% 33%] carrier frequency 1.8 GHz.

The theoretical and simulated parameters of CH21, CH22 and CH24 are given in Table 1, Table 2 and Table 3.

A number of different cases of mobile radio channels have been simulated in this work. These channels have different number of reflected paths and with different power distribution in the respective paths. Extensive computer simulation

Table 1. Simulation results of two paths Rayleigh channel (CH 21).

Parameter	Theoretical Value	Practical value
Mean of Rayleigh Path 1	0.6267	0.6537
Mean of Rayleigh Path 2	0.6267	0.6537
Variance of Rayleigh Path1	0.1073	0.0915
Variance of Rayleigh Path2	0.1073	0.0915
Mean of q_1	0	−0.0029
Mean of q2	0	−0.0115
Mean of q_3	0	−0.0029
Mean of q4	0	−0.0115
Variance of q1	0.25	0.25
Variance of q_2	0.25	0.25
Variance of q3	0.25	0.25
Variance of q4	0.25	0.25

Table 2. Simulation results of two-path. Rayleigh channel (CH 22).

Parameter	Theoretical Value	Practical value
Mean of Rayleigh Path 1	0.7927	0.8390
Mean of Rayleigh Path 2	0.3965	0.4012
Variance of Rayleigh Path1	0.1717	0.2089
Variance of Rayleigh Path2	0.0429	0.0410
Mean of q_1	0	0.0001
Mean of q2	0	−0.1807
Mean of q_3	0	−0.0360
Mean of q4	0	0.0265
Variance of q1	0.4	0.4000
Variance of q_2	0.4	0.4708
Variance of q3	0.1	0.1000
Variance of q4	0.1	0.1000

Table 3. Simulation results of three-path. Rayleigh channel (CH 24).

Parameter	Theoretical Value	Practical value
Mean of Rayleigh Path 1	0.5117	0.5030
Mean of Rayleigh Path 2	0.5117	0.5137
Mean of Rayleigh Path 3	0.5117	0.5106
Variance of Rayleigh Path1	0.0715	0.0824
Variance of Rayleigh Path2	0.0715	0.0718
Variance of Rayleigh Path3	0.0715	0.0932
Mean of q_1	0	−0.0255
Mean of q2	0	0.0461
Mean of q_3	0	−0.0477
Mean of q4	0	−0.0262
Mean of q5	0	−0.0178
Mean of q6	0	−0.0303
Variance of q1	0.1667	0.1667
Variance of q_2	0.1667	0.1667
Variance of q3	0.1667	0.1667
Variance of q4	0.1667	0.1667
Variance of q5	0.1667	0.1667
Variance q6	0.1667	0.1667

tests have been carried out to verify and confirm that the simulated channels have the measured characteristics that closely match with theoretical design values as shown above.

A baseband model of the data transmission system and the 4−level Quadrature Amplitude Modulation (4−QAM) has been employed in this investigation.

The performance of nonlinear equalizer for channels CH21, CH22 and CH24 is illustrated in Fig. 6. Figure 6 shows the results for different number of paths viz. 2−path and 3−path channel models. As can be seen from Fig. 3 NLE performs better for CH22 where the power distribution is [80% 20%]. In case of CH24 which is a three-path fading channel with equal power distribution NLE do not perform much better. Figure 7 shows the performance curve for the channel CH24 using NLE and NMLD. It can be seen clearly that the performance o NMLD is must better than the performance of NLE. The gap of BER becomes widen when SNR increases, which express that for high signal to noise ratio where NLE nearly fails, NMLD works impressive.

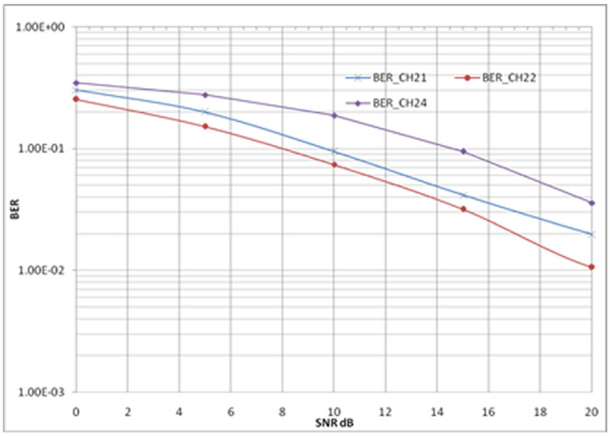

Fig. 6. Performance of the nonlinear equalizer.

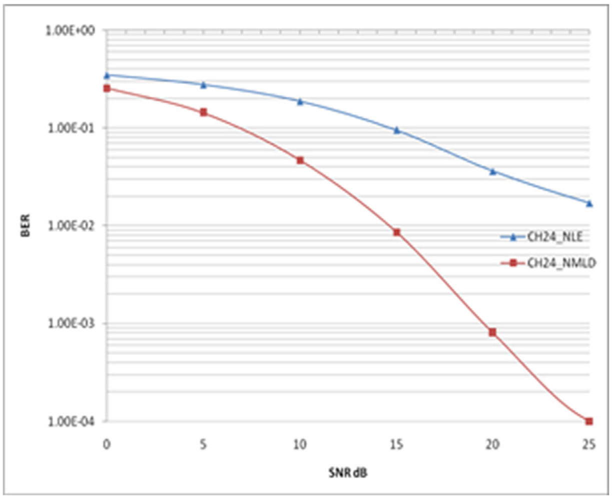

Fig. 7. Performance of the Nonlinear Equalizer and NMLD for worst case three paths channels.

5. Conclusion

Although, the results of nonlinear equalizers are acceptable in compression to the detection error produced by the linear equalizers, but it nearly fail or gives the bad performance for the worst case channel which is almost impossible. The performance of NML detection for systems such as those expected in the next generation mobile radio applications have been mainly focused in this paper. For the worst case mobile radio channels with three independent paths where the NLE generally fails or gives very bad results, the performance of NMLD is very impressive. The results have shown that the NML detector has performed impressively under severe ISI conditions and therefore it can be concluded that the NML detector performs much better than the nonlinear equalizer in case of the worst case channels. Since this NMLD can withstand such a 'worst case' ISI, then this detector will be unlikely to have poor performance over any practical wideband channel that may be encountered in a mobile radio environment.

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