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Error Rate Analysis of Multi-carrier Modulation Using Differentially Encoded and Detected 16 DE-APSK under Rician Fading Channels

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Abstract: The Multi carrier (MC) Transmission Technique was devised in the 1960's for voice band data transmission. Today there are two principles of multi carrier applications, one is for the high speed digital subscriber loop and the other is for the broadcasting of digital audio and video signals. In this work the use of MC for high-bit rate wireless applications is considered.

The bit error rate (BER) performance of MC utilizing differentially encoded 16 level amplitude phase shift keying (16 DE-APSK) and differentially coherent demodulation in frequency flat fading channels is considered via the use of Monte Carlo simulation methods. The BER results are presented for MC utilizing (16 DE-APSK) modulation and with MC utilizing differentially encoded 16 level phase shift keying (16 DE-PSK) modulation and MC utilizing differentially encoded 16 quadrature amplitude modulation (16 QAM) for frequency flat Rician channel in the presence of additive white Gaussian noise (AWGN). The performance of MC is also compared with equivalent single (16 DE-APSK) carrier systems.

Key words: Multi carrier, fading channels, 16 star QAM, 16 DE-APSK,16 DPSK, wireless and mobile communications

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Introduction

The development of Multi carrier modulation techniques (MCMT) (Chang and Gibby, 1968) has allowed the transmission of high quality audio and digital television pictures to be demonstrated from both terrestrial and satellite based systems (Shelswell, 1995; Sari ***et al.***, 1995; Carrasco ***et al.***, 1992). The aim of this paper is to investigate the use of (MCMT) for high bit rate wireless applications. In order to improve spectral efficiency the use of differentially encoded (16 DE-APSK) is employed to modulate the parallel carriers (Webb ***et al.***, 1991). (MCMT) is a wideband modulation scheme which is specifically designed to cope with the problems of multi path reception. It achieves this by transmitting a large number of narrowband digital signals over a wide bandwidth. The consequently longer symbol duration renders the system less susceptible to the effects of inter symbol interference (ISI) induced by a frequency selective channel. To achieve the aim of (MCMT) the sub-carrier frequencies are chosen to be spaced at the symbol rate, that is, if the MC symbol duration is T_s seconds, the sub-carrier frequency spacing is $1/T_s$ Hz (Chang, 1966).

System simulation

A basic (MCMT) system can be simulated as shown in Fig. 1. Firstly the data symbols from the (16 DE-APSK) modulator are converted from serial to parallel (S/P) format. In the simulations the output width of the converter is 16 symbols (complex valued), which corresponds with the number of parallel carriers in the MCMT signal at the output of the inverse Fast Fourier transform (IFFT) block. The output of IFFT is the time domain MC signal which has 16 complex valued samples (Weinstein, 1971; Qatawneh, 2002). These samples are converted from parallel to serial format before being placed on to the channel. In the receiver, the incoming signal is converted back to a parallel format before being processed by the Fast Fourier transform (FFT) which implements the demodulator. The FFT output represents the parallel demodulated symbols which are converted back into the original serial format. These symbols are then differentially coherently demodulated to recover the data. The data formats employed at the input to the IFFT block will be described where required.

In the presence of inter-symbol interference caused by the transmission channel, the properties of orthogonality between the carriers is no longer maintained. However, by preceding each symbol by a guard period it is possible to absorb the inter-symbol interference. This is achieved using the optional guard period add block shown in Fig. 1. This guard period is removed at the receiver by the complementary guard period remove block. The guard period must be of limited duration (Shelswell, 1995), because although a longer guard period gives a more rugged system, it imposes a penalty because of the power required for its transmission. If is the guard period, the duration of transmitted signal is given by $t_S=\Delta+T_S$ where is the MC symbol period. In this case the guard period is created by taking the last four samples of the 16 time domain samples at the output of the IFT and then inserting them in front of the 16 original samples. Consequently, there are now 20 samples per M C symbol.

Differential 16 Star QAM

The majority of work concerning QAM for mobile radio applications has utilized square QAM constellations. In general 16 QAM (square) requires coherent detection. However, since the performance of coherent detection is severely affected by multi path fading, (mainly because of carrier recovery issues), the 16 Star QAM constellation shown in Fig. 2 combined with differentially coherent detection is preferred (Webb ***et al.***, 1991).

Modulator structure for 16 DAPSK

The modulator structure for 16 Star QAM(16DAPSK) is shown in Fig. 3. The random data source gives a binary sequence, which is formed into four bit symbols namely, a_n,b_n,c_n,d_n. The carrier is differentially phase modulated by the last three bit, b_n, c_n, d_n and differentially amplitude modulated by the first bit a_n. The first bit a_n is used to determine the transmitted signal amplitude as follows. If the incoming bit a_n is a binary '1' the amplitude level of the transmitted signal is changed to the other amplitude level. However, if the incoming bit a_n is a binary '0' the amplitude level of the transmitted signal remains the same as shown in Table 1. The remaining three bits, b_n, c_n, d_n are Gray encoded to give the phase changes shown in Table 2.

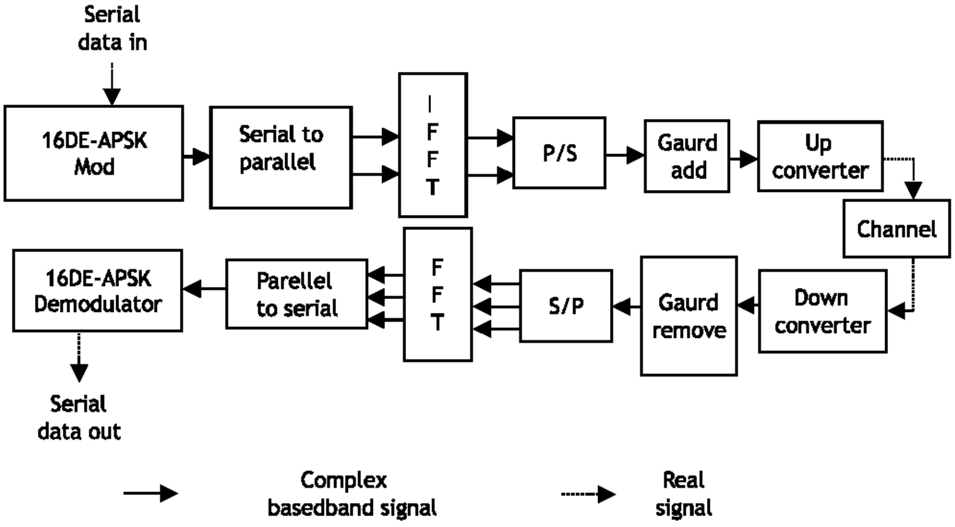

Fig. 1: Basic MCM system simulation model

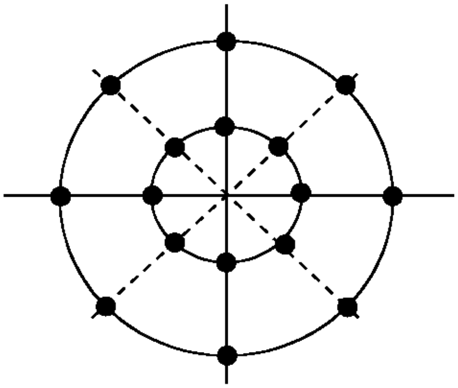

Fig. 2: 16 level star QAM constellation

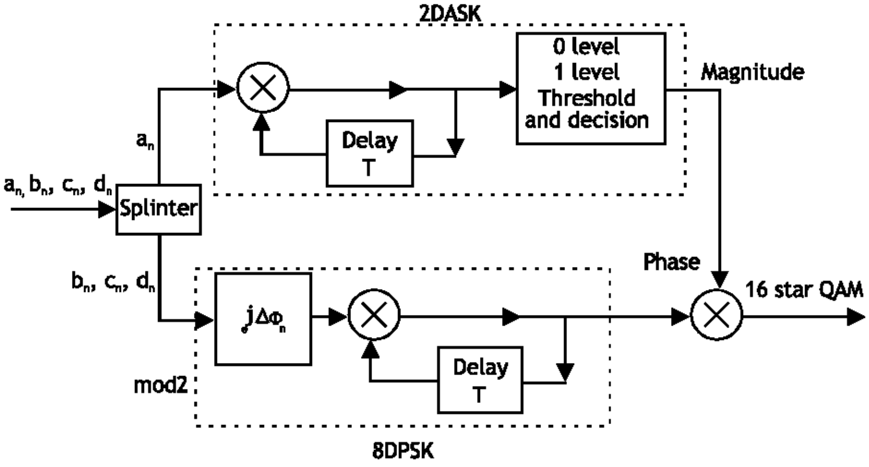

Fig. 3: Modulator structure for 16 DAPSK (16 Star QAM)

Table 1: Amplitude bit change

Information symbol, a_n	Amplitude change
0	No
1	Yes

Table 2: 16 Star QAM phase change

Information bits b_n,c_n,d_n	Phase change (degrees)
000	0
001	45
011	90
111	135
101	180
100	225
110	270
010	315

Consequently it can be seen that a differential 16 star QAM is a combination of independent 8 DPSK and 2 DASK.

For example, suppose that the current input bits $\{b_n,c_n,d_n\}$ are "000" and the previous transmitted phase 0° is, it can be seen from Table 2 that the required phase change is zero degrees giving a transmitted phase of 0°.

For example, suppose that the current input bits $\{b_n,c_n,d_n\}$ are "000" and the previous transmitted phase is, it can be seen from Table 2 that the required phase change is zero degrees giving a transmitted phase of 0°.

How to detect a differential 16 DE-APSK signal

Differential detection of Differential 16 DE-APSK signal can be split into two stages: first the differential phase detector (DPD) for the eight PSK signal and second the differential amplitude ratio detection (DARD) of the two level amplitude signal. Fig. 4 shows Demodulator structure for 16DE-APSK. The DPD and DARD detectors detect the phase difference and amplitude ratio of the two successive received signals, respectively and their respective outputs are given by :

$$\Delta\Psi_n = \arg Z_n . Z^*_{n-1} \tag{1}$$

The * denote the complex conjugate
And

$$\Delta\tilde{R}_n = \frac{|Z_n|}{|Z_{n+!}|} \tag{2}$$

The decision rule is to find

$\Delta\Phi_n$, from: ($m\pi l$ 4, m=0-7)

Where $\Delta\Phi_n$, is -closest-to-$\Delta\Psi_n$

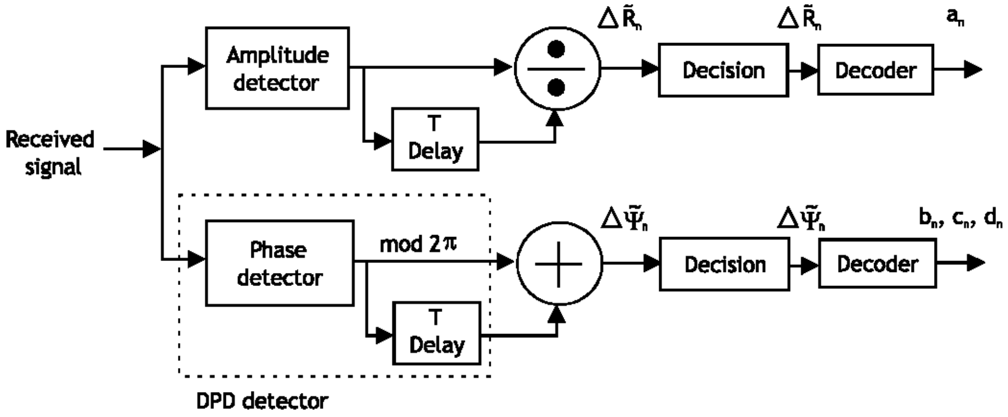

Fig. 4: Demodulator structure for 16DE-APSK

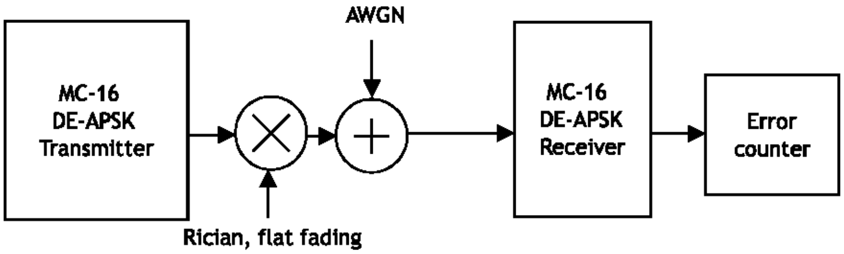

Fig. 5: MC-16 DE-APSK system and channel

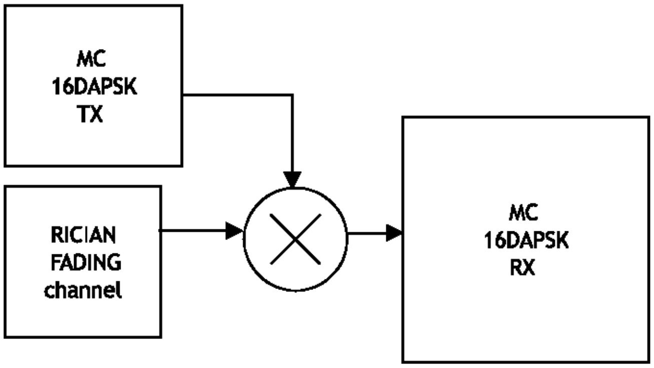

Fig. 6 : Rician fading with MC-16 DE-APSK model

Which is chosen from :

$$(K^{-1}, 1, K)$$

$$\Delta\bar{R}_n = 1, \text{if}\, \Delta R_{l1} \leq \Delta\tilde{R}_n \leq \Delta R_{l2} \qquad (3)$$

$$\Delta\bar{R}_n = K,\ \text{if}\, \Delta R_{l2} \angle\, \Delta\tilde{R}_n \tag{4}$$

$$\Delta R_{L1} = \frac{1+K^{-1}}{2}\ \text{and}\ \Delta R_{l2}\ \frac{1+K}{2} \tag{5}$$

$$\Delta\bar{R}_n = k^{-1}, \text{if}\, \Delta\tilde{R}_n \angle\, \Delta R_{l1} \tag{6}$$

where ΔR_{l1} and ΔR_{l2}, are-the-decision-thresholds

The transmitted four bit $s(a_n b_n c_n d_n)$ is recovered from $\Delta\Phi_n$ and ΔR_n

$$SNR=S/\sigma^2+D/\sigma^2=(1+k)\ D/\sigma^2 \tag{7}$$

$k=\frac{S}{D}$, where k is so called k factor of Rician fading, S is the power of the specular component, D is the power of the defuse component and σ^2 is the variance

Flat fading channels

A typical channel model in land mobile radio is known as frequency flat Raleigh fading. Rician fading may be characterized by a factor which is defined as the power ratio of the specular (line of sight or direct path) component to the diffuse components. Fig. 5 shows MC-16 DE-APSK system and channel. The rate of change of the fading is defined by the Doppler rate. The Doppler rate is proportional to the velocity of the mobile station and the frequency of operation. The normalized Doppler rate is given by $f_d T_s$ where f_d is the maximum Doppler rate and T_s is the MC symbol duration. For the considered simulations, the symbol duration is equal to one second so that the normalized Doppler rate is equal to the Doppler rate. In general, normalized Doppler rates less than 0.01 are applicable to most systems.

A more complex propagation model includes many discrete scatters, where each propagation path may have a different amplitude, propagation delay and Doppler shift. When the components of a signal are received with different delays, the phase difference between them is a function of the frequency of the components. Thus the transmitted signal will experience a channel with a non-flat frequency response, which also varies with time. This type of channel is said to be frequency selective and is usually modeled as a tapped delay line, where the number of taps is equal to the number of discrete delayed paths. Clearly, the effect of the tapped delay line is to introduce overlap between the transmitted symbols. This form of degradation is known as inter-symbol interference (ISI). In this model the first arriving path experiences Rician fading. In this work, the ratio k for the Rician fading path is equal to 15 for all the simulations. Fig. 6 shows the simulation model

Results and BER evaluations

Performance of multi carrier differential encoded 16 DE-APSK and single 16 DE-APSK in the presence of AWGN

We wish to establish benchmark AWGN for Multi carrier Differential encoded (DE. 16 DE-APSK and single 16 DE-APSK in the presence of AWGN with differentially coherent demodulation. In this section the BER performance of Multi carrier Differential encoded (DE. 16 DE-APSK and single 16 DE-APSK with a guard period disturbed by AWGN are compared. Fig. 7 shows the BER results as a function of signal to noise ratio (SNR) for both a single carrier and for an MC system using differential 16 DE-APSK encoding. Clearly the BER performances are not identical in AWGN. This is to be expected owing to the noisy phase reference used in the differential systems.

Also Fig. 8 Compares the BER performance for Multi carrier 16 DE -APSK and single 16 DE-APSK and single 16 DPSK in the presence of AWGN

For example the result of Comparison shows that the BER performance for Multi carrier 16 DE-APSK and single 16 DE -APSK and single 16DPSK in the presence of AWGN are not the same as shown in Fig. 8. If we choose SNR ratio for instant 15 dB, then the BER performance for Multi carrier 16 DE-APSK is equal 10^{-7} and the BER performance for 16 DPSK is equal 10^{-4}, but the BER performance for 16 DE-APSK is equal 7×10^{-5}

Performance of Multi carrier Differential Encoding 16 DE-APSK with Differentially Coherent Demodulation in Rician Fading Channels

The BER performances presented in Fig. 9 compare Multi carrier 16 DE-APSK in the Gaussian channel ($k=\infty$) and for various values of the Rician fading power ratio (k) and a Doppler rate of $f_d=0.01$ Hz. It can be observed that the Rician channel degrades the SNR performance of the MC systems by about 6 dB compared with that achieved over the Gaussian channel at a BER of 1×10^{-3}.

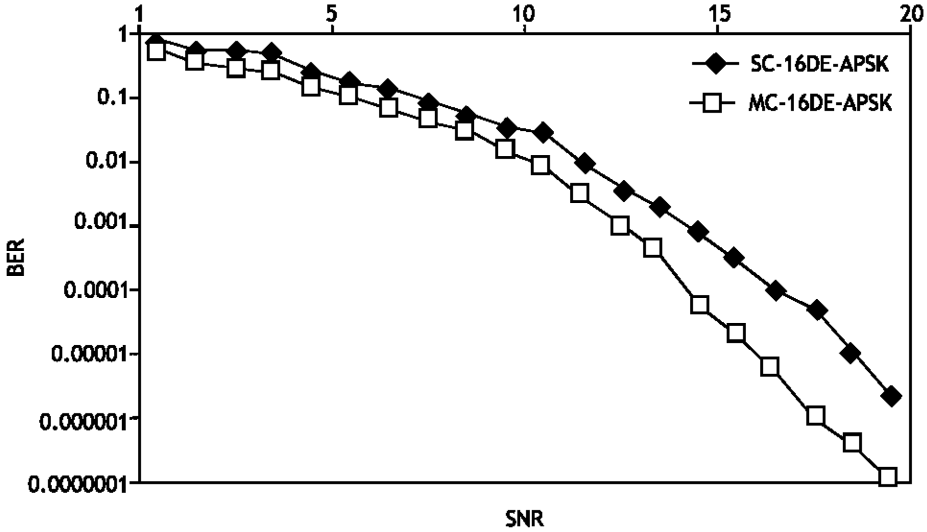

Fig. 7: Multi carrier 16 DE-APSK and single 16 DE-APSK in the presence of AWGN

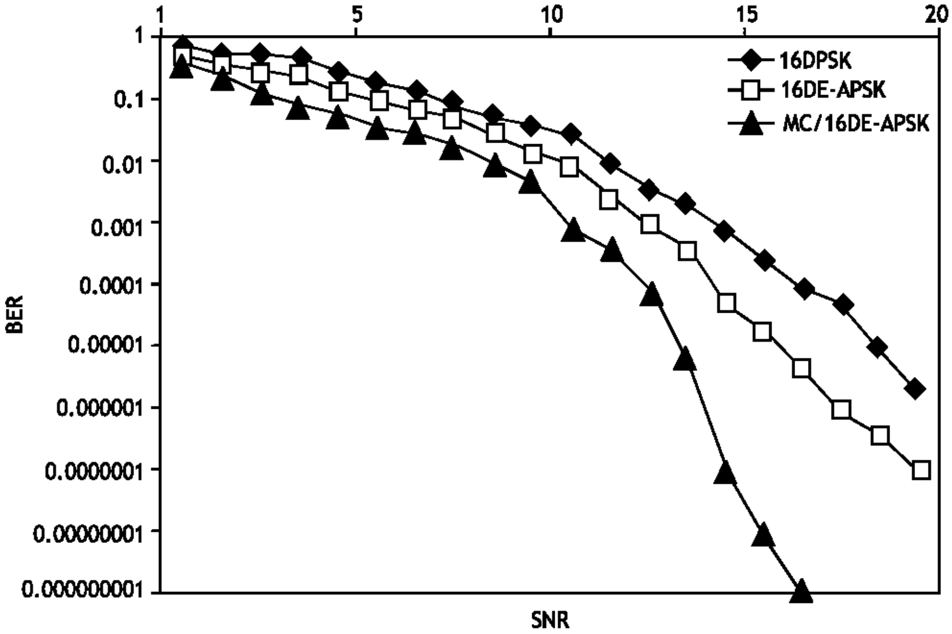

Fig.8: Comparison of Multi carrier 16 DE -APSK and single 16 DE -APSK and single 16 DPSK in the presence of AWGN

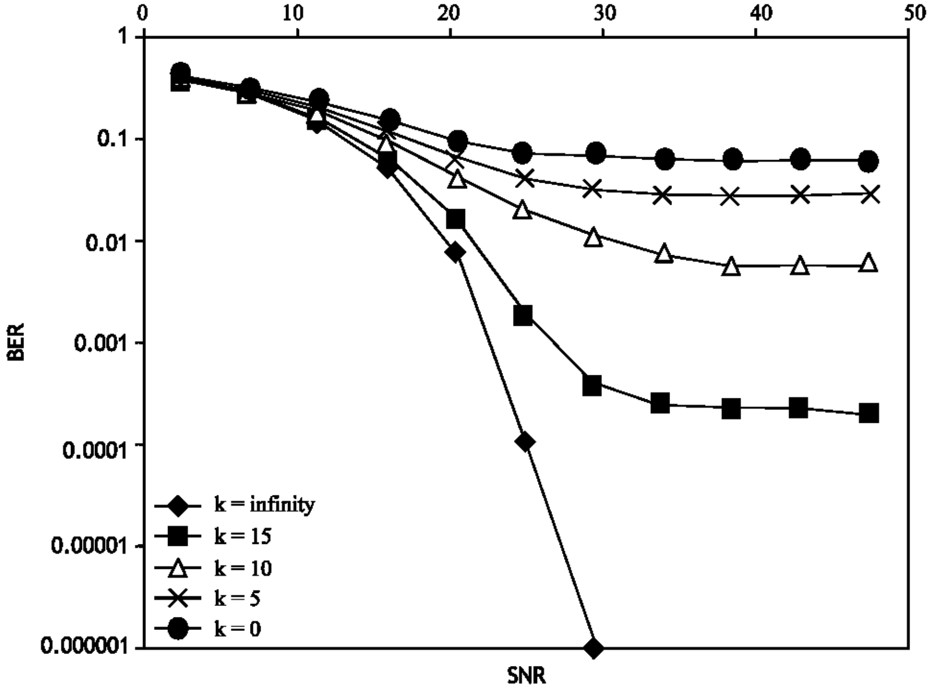

Fig. 9: Comparison of Multi carrier 16 DE-APSK in the Gaussian channel (k=∞) and for various values of the Rician fading power ratio (k) and a Doppler rate of f_d=0.1 Hz

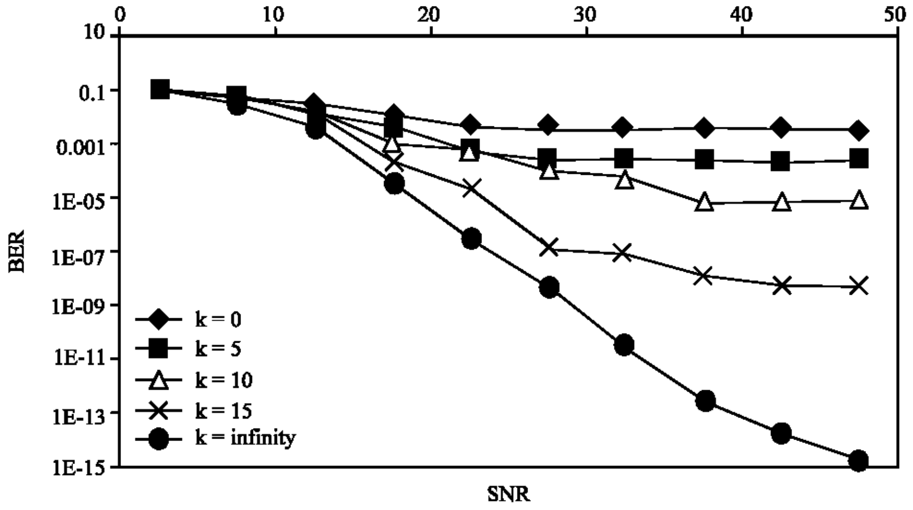

Fig. 10: Performance of Multi carrier 16 DE-APSK in presence of Gaussian channel (k=∞) and for various values of the Rician fading power ratio (k) and a Doppler rate of f_d=0.01 Hz

The single channel system performance is some 3 dB worse than the OFDM system at the same BER in the Rician channel. The irreducible BER is also higher for the single channel system.

Fig. 9 compares the performance of Multi carrier 16 DE-APSK in the Gaussian channel (k=∞) and for various values of the Rician fading power ratio (k) and a Doppler rate of f_d=0.1 Hz

The simulation results presented in Fig. 10 show the performance of Multi carrier 16 DE-APSK in presence of Gaussian channel (k=∞) and for various values of the Rician fading power ratio (k) and a Doppler rate of f_d=0.01 Hz with differentially coherent demodulation It can be seen that the BER become irreducible for all the simulated values of k except for the AWGN case of k=∞.

The BER performance of Rician faded for Multi-carrier 16 DE-APSK and single 16 DE-APSK with differentially coherent demodulation in the presence of AWGN is considered. The BER performance was presented for various values of k factor. With a Doppler rate 0.1 Hz and 0.01 Hz. It was shown that the BER performance improves as k factor increases (specular components becomes stronger). When specular component (k=15) Rician channel, the required value of signal to noise ratio(SNR) is 35 dB at BER=2×10^{-9} for Doppler rate 0.01 Hz. But for Doppler rate 0.1 Hz, the required value of signal to noise ratio (SNR) equal 35 dB at BER=4×10^{-4}.

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