Performance of orthogonal frequency division multiplex utilising differential quadrature amplitude modulation in AWGN and Rician fading channels

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The multicarrier transmission technique known as Orthogonal Frequency Division Multiplexing (OFDM) was devised in the 1960's for voiceband data transmission. Today there are two principle OFDM applications, one is for the high speed digital subscriber loop and the other is for the broadcasting of digital audio and video signals. We will consider the use of OFDM for high-bit rate wireless applications. The Bit Error Rate (BER) performance of OFDM utilising Differentially Encoded (DE) 16 star Quadrature Amplitude Modulation (QAM) 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 OFDM with 16 QAM (OFMDM/16 QAM), OFDM De- Encoded 16 QAM (OFDM/DE-16 QAM) for frequency flat Rician channel in the presence of Additive White Gaussian Noise (AWGN). The performance of OFDM is also compared with equivalent single carrier systems.

ان نظام الارسال متعدد الترددات الحاملة المعروف التقسيم الترددي المضاعف المتعامد (OFDM) الذي ظهر اول مره في ستينات القرن الماضي لاغراض نقل المعلومات على القنوات المخصصه لنقل الكلام , يستخدم اليوم في تطبيقين : اولهما لانشوطة المشترك الرقمية ذات السرعة العالية وثانيهما للبث الاذاعي الرقمي لاشارات الصوت والصورة . يهتم هذا البحث في استخدام نظام (OFDM)لتطبيقات المعدل العالي لنقل المعلومات لاسلكياً . اداء نظام (OFDM) وفق معدل الخطأ قد تم دراسته في هذا البحث مستخدماً نظام تضميني مقداري متعامد (QAM)– 16نجمي–ونظام كشف متزامن تفاضلي وقناة ذات خفوت مسطحة التردد . اعتمد نظام محاكاه حسب طريقة مونت كارلو . إن نتائج دراسة معدل الخطأ تقدم هنا لنظام OFDM/16QAM و OFDM/DE-16 Star QAM لقناة بتردد مسطح ريساني وآخر بتردد مسطح ريلي وضوضاء بيضاء مضافه جاوسية التوزيع (AWGN) وتمت مقارنة اداء نظام (OFDM) مع نظام مكافيء له يستخدم تردد حامل منفرد .

Keywords: OFDM, Fading channels, Star QAM, Wireless and mobile communications

1. Introduction

The development of Orthogonal Frequency Division Multiplex (OFDM) techniques [1] has allowed the transmission of high quality audio and digital television pictures to be demonstrated from both terrestrial and satellite based systems [2-4]. The aim of this paper is to investigate the use of OFDM for high bit rate wireless applications. In order to improve spectral efficiency the use of Differentially Encoded (DE) 16 star Quadrature Amplitude Modulation (QAM) is employed to modulate the parallel carriers [5]. OFDM is a wideband modulation scheme which is specifically designed to cope with the problems of multipath 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 orthogonality, the sub-carrier frequencies are chosen to be spaced at the symbol rate, that is, if the OFDM symbol duration is T_s seconds, the sub-carrier frequency spacing is $1/T_s$ *Hz* [6].

2. System simulation

A basic OFDM system can be simulated as shown in fig. 1. Firstly the data symbols from the DE 16 Star QAM modulator are converted from Serial to Parallel (S/P) format. In our simulations the output width of the converter

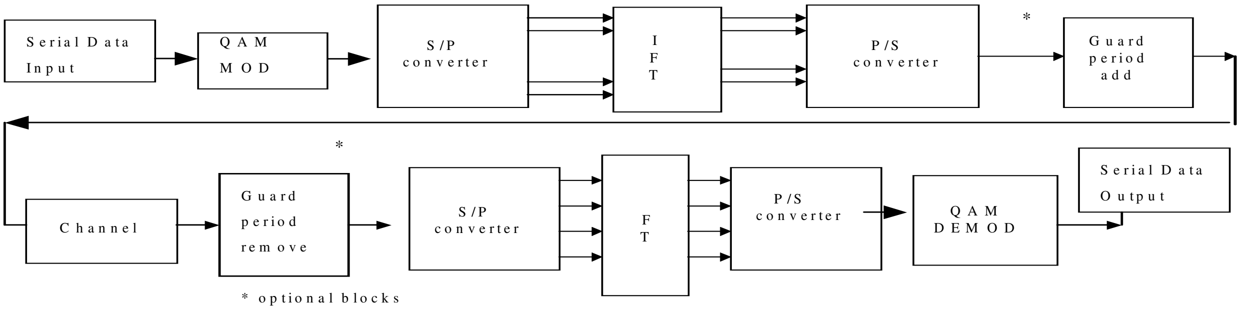

Fig. 1. Basic OFDM system simulation model.

is 16 symbols (complex valued) which corresponds with the number of parallel carriers in the OFDM signal at the output of the Inverse Fourier Transform (IFT) block. The output of IFT is the time domain OFDM signal which has 16 complex valued samples [7]. 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 Fourier Transform (FT) which implements the demodulator. The FT 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. In addition, in a number of our simulations the S/P conversion process at the input to the IFT is more than a simple one to one mapping of the symbols from input to output. The data formats employed at the input to the IFT block will be described where required.

In the presence of intersymbol 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 [3], because although a longer guard period gives a more rugged system, it imposes a penalty because of the power required for its transmission. If Δ is the guard period, the duration of transmitted signal is given by $t_s = \Delta + T_s$, where is T_s is the OFDM 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 OFDM symbol.

2.1. Differential 16 star QAM

The majority of work concerning QAM for mobile radio applications has utilised square QAM constellations. In general 16 QAM (square) requires coherent detection. However, since the performance of coherent detection is severely affected by multipath fading, (mainly because of carrier recovery issues), the 16 Star QAM constellation shown in fig. 2 combined with differentially coherent detection is preferred [5].

2.1.1. Modulator

The modulator structure for 16 Star QAM 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

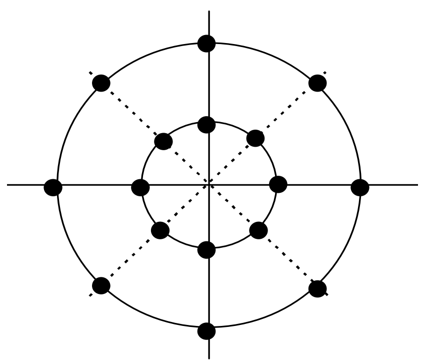

Fig. 2. 16 level star QAM constellation.

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

2.1.2. Differential coherent demodulator

The Differential detection of a 16-star QAM signal can be split into two parts: first the differential phase detector for the 8 PSK signal and second the differential detection of the two level the amplitude signal. Supose amplitude levels of the transmitted signal are L_1 and L_2. Now suppose the received amplitudes at time T_n and T_{n+1} are $|Z_n|$ and $|Z_{n+1}|$ respectively. The function of the differential amplitude demodulator is to identify any significant change of the received amplitude which indicate the transmission of a binary '1'. The decision circuit shown in fig. 4 employs two adaptive thresholds to make this decision according to the following rules [6].

$$|Z_{n+1}| \geq \left(\frac{L_1 + L_2}{2} \right) |Z_n| \qquad (1)$$

or if:

$$|Z_{n+1}| < \left(\frac{2}{L_1 + L_2} \right) |Z_n|. \qquad (2)$$

In our system; L_1 = 1, and L_2 = 3, consequently eq. (1) becomes,

$$|Z_{n+1}| \geq 2 \; |Z_n|, \qquad (3)$$

and eq. (2) becomes

$$|Z_{n+1}| < 0.5 \; |Z_n|. \qquad (4)$$

The decision block implemented in fig. 4 consists of two comparators, the upper comparator implements eq. (3) while the lower comparator implements eq. (4). The outputs of two comparators are fed to an OR-gate to combine their decisions decisions as shown in table 3.

Now we have to decode the differential phase signal. Suppose the received symbol phases are β_n and β_{n+1} at T_n and T_{n+1}, respectively. We must calculate the phase difference $\Delta\beta_n$ between these two phases to estimate the transmitted symbol. To do this the current input sample Z_{n+1} is multiplied by the complex conjugate of the previous sample Z_n as shown in fig. 5 the argument of this complex valued result yields the phase difference $\Delta\beta_n$. The phase difference is then mapped to the corresponding 3-bit output using the 8PSK slicer. The resulting binary

Table 1
Amplitude bit change

Information symbol, a_n	Amplitude change
0	No
1	Yes

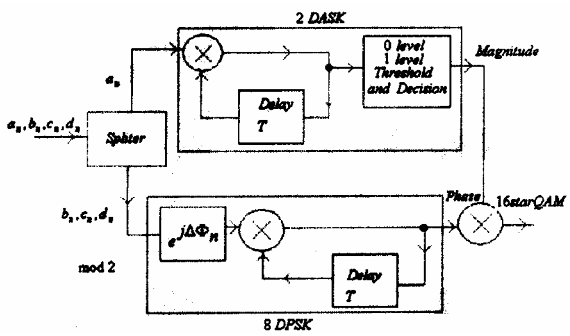

Fig. 3. Modulator structure for 16 star.

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

data from the magnitude and phase decisions are merged to give the final serial output data.

2.2. Fading channel simulation models

Because we are interested in mobile and wireless applications we must utilise the appropriate radio channel models in our simulations.

2.2.1. Flat fading channels

Because we are interested in mobile and wireless application we must utilise appropriate radio channel models in our simulations. A typical channel model in land mobile radio is known as frequency flat Raleigh fading. This model is suitable for modelling urban areas that are characterised by many obstructions, e.g. buidings, surrounding the mobile station where a line of

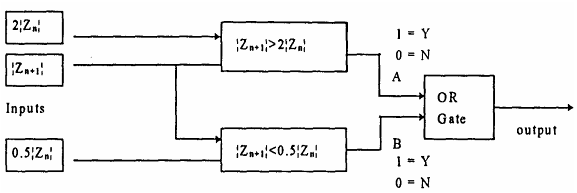

Fig. 4. Decision block diagram.

Table 3
Magnitude bit decision

A	B	Output
0	0	0
0	1	1
1	0	1
1	1	*

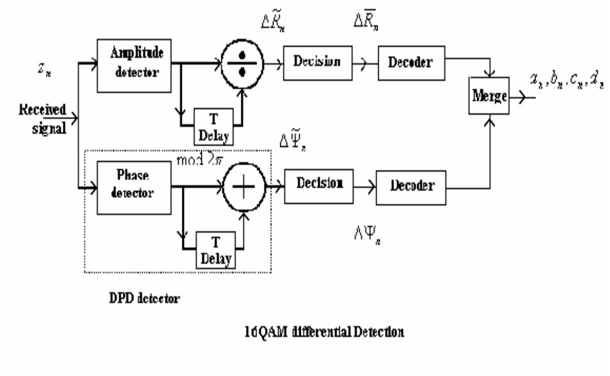

Fig. 5. DE 16 star QAM decoder.

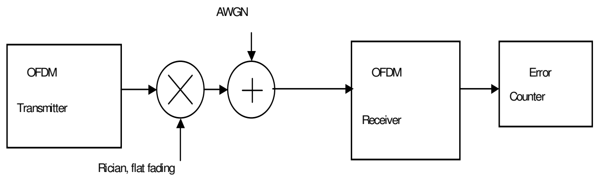

Fig. 6. OFDM system and channel.

sight path not exist. In suburban areas, a line of sight path may exist between transmitter and receiver and this will give rise to Rician fading [9]. Rician fading may be characterised by a factor which is defined as the power ratio of the specular (line of sight or direct path) component to the diffuse components. This ratio a, defines how near to Rayleigh statistics the channel is. In fact, when $a = 0$ we have Rayleigh fading and there is no fading at all when $a = \infty$. Fig. 6 shows the simulation block diagram. 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 normalised Doppler rate is given by $f_d\ T_s$ where f_d is maximum Doppler rate and T_s is the OFDM symbol duration. For our simulations, the symbol duration is equal to one second so that the normalis Doppler rate is equal to the Doppler rate. In general, normalised 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 varies with time type of channel is said to be frequency selective and is usually modelled 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 intersymbol interference (ISI). In this model the first arriving path experiences Rician fading in our work, the ratio a for the Rician fading path is equal to 15 for all the simulations. Fig. 7 shows the simulation model.

3. Results and BER evaluations

3.1. Performance of OFDM OFDM/DE/16 star QAM in AWGN

We wish to establish benchmark AWGN performances for single carrier differentially encoded 16 star QAM and for DE-16 star QAM /OFDM systems with differentially coherent demodulation. In this section the BER performance of OFDM/ DE16 star QAM with a guard period and single carrier DE16 star QAM disturbed by AWGN are compared. Fig.8 shows the BER results as a function of Signal to Noise Ratio (SNR) for both a single carrier and for an OFDM system using differential 16 star QAM encoding. Clearly the BER performances are identical in AWGN. This is to be expected owing to the noisy phase reference used in the differential systems.

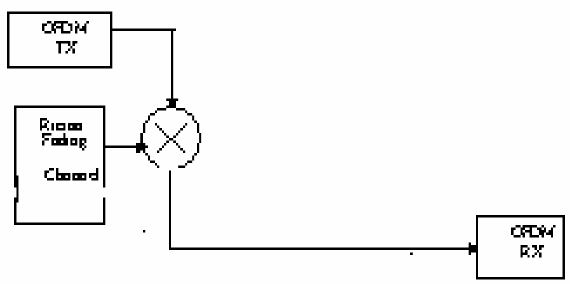

Fig. 7. Rician fading with OFDM model.

3.2. Performance of OFDM/ 16 star QAM with differential encoding and differentially coherent demodulation (OFDM/DE- 16 star QAM) in Rician fading channels

The BER performances presented in fig. 9 compare single channel and OFDM systems using DE 16 star QAM in the Gaussian channel ($a = \infty$) and a specular Rician channel (a = 15). It can be observed that the Rician channel degrades the SNR performance of the OFDM systems by about 6 dB compared with that achieved over the Gaussian channel at a BER of 1×10^{-3}. 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.

Presence of AWGN and Rician fading, a = 15. The simulation results presented in fig. 10. show the performance OFDM/DE 16 star QAM with differentially coherent demodulation, in the presence of AWGN for various values of the Rician fading power ratio (a) and a Doppler rate of f_d = 0.01 *Hz*. It can be seen that the BERs become irreducible for all the simulated values of a except for the AWGN case of $a = \infty$. That said, for the specular Rician channel a = 15, the BER results are only some 5 dB worse than the AWGN case at a BER of 1×10^{-3} . The irreducible BER is about 1×10^{-4} for this situation which could be reduced by the use of forward error correction.

3.3. Performance of OFDM/DE 16 star QAM, using single source per channel multiplex in AWGN with the Rician channel

This time we multiplex a single DE 16 star QAM source on to one of the sixteen OFDM channels and pad the remaining channels with suitable data. The simulation BER results are shown in fig. 11. various Rician channels. It can be observed that these results are slightly worse than those shown in fig. 10 which correspond with the previous multiplexing scenario. This is because the symbols from the independent source are subject to larger channel induced phase changes than those experienced by the scenario relevant to fig. 10.

4. Conclusions

The BER performance of Rician faded for OFDM/ 16 Q AM, OFDM/DE-16 QAM with differentially coherent demodulation in the presence of AWGN is considered. BER performance were presented for various values of a factor with a Doppler rate 0.1. It was shown that the BER performance improves as a factor increases (specular components becomes stronger). When specular component (a=15) Rician channel, the required value of signal to noise ratio (SNR) at BER = 6 x 0.0001.

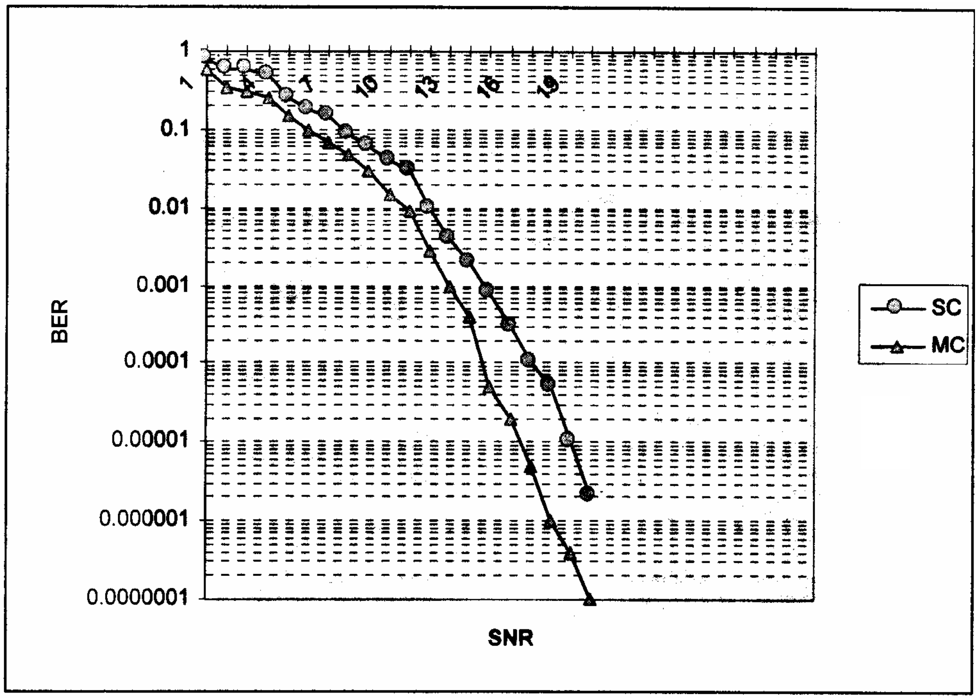

Fig. 8. OFDM/DE 16 star QAM and single DE 16 star QAM in the presence of AWGN.

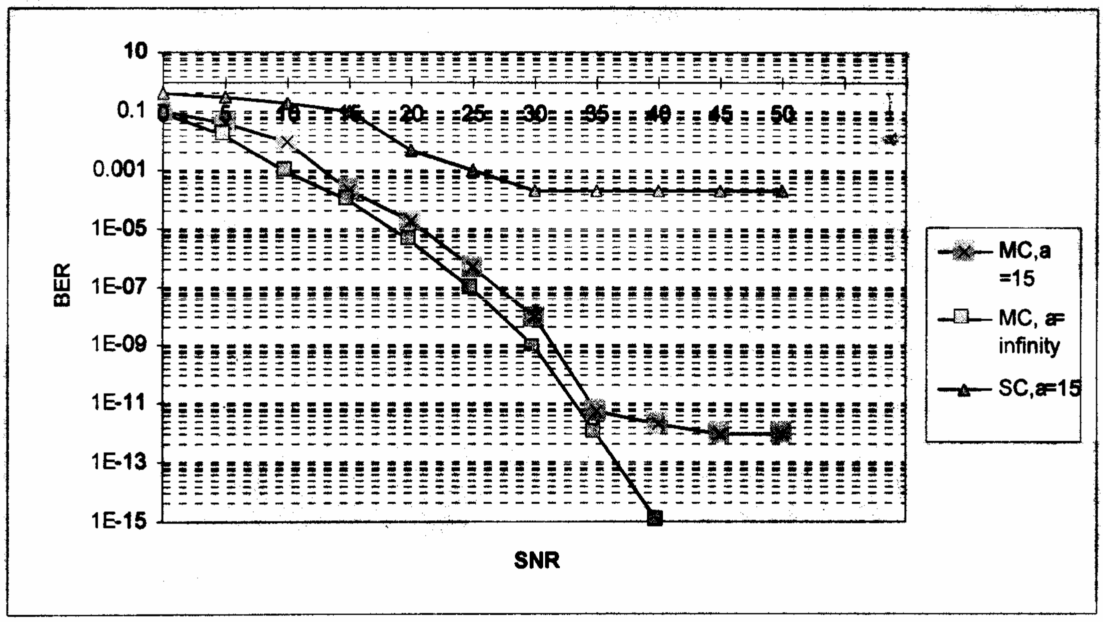

Fig. 9. Comparison of DE 16 star QAM used in both single carrier and OFDM systems in the presence of AWGN and Rician fading , a =15. and a Doppler rate of f_d = 0.01 Hz.

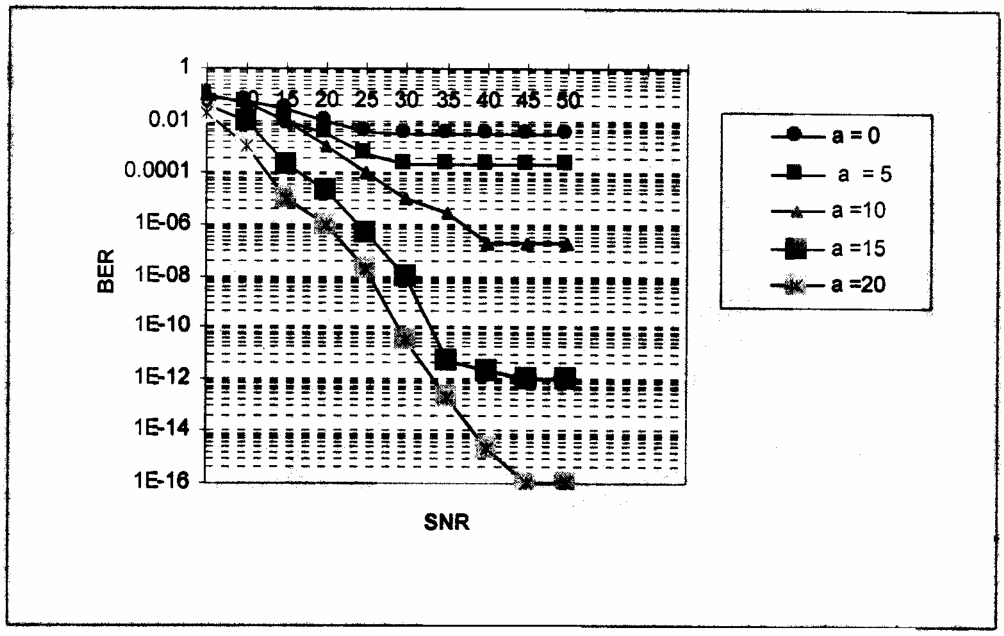

Fig.10. Performance OFDM/DE 16 star QAM with differentially coherent demodulation, in the presence of AWGN for various values of the Rician fading power ratio (*a*) and a Doppler rate of f_d= 0.01 Hz.

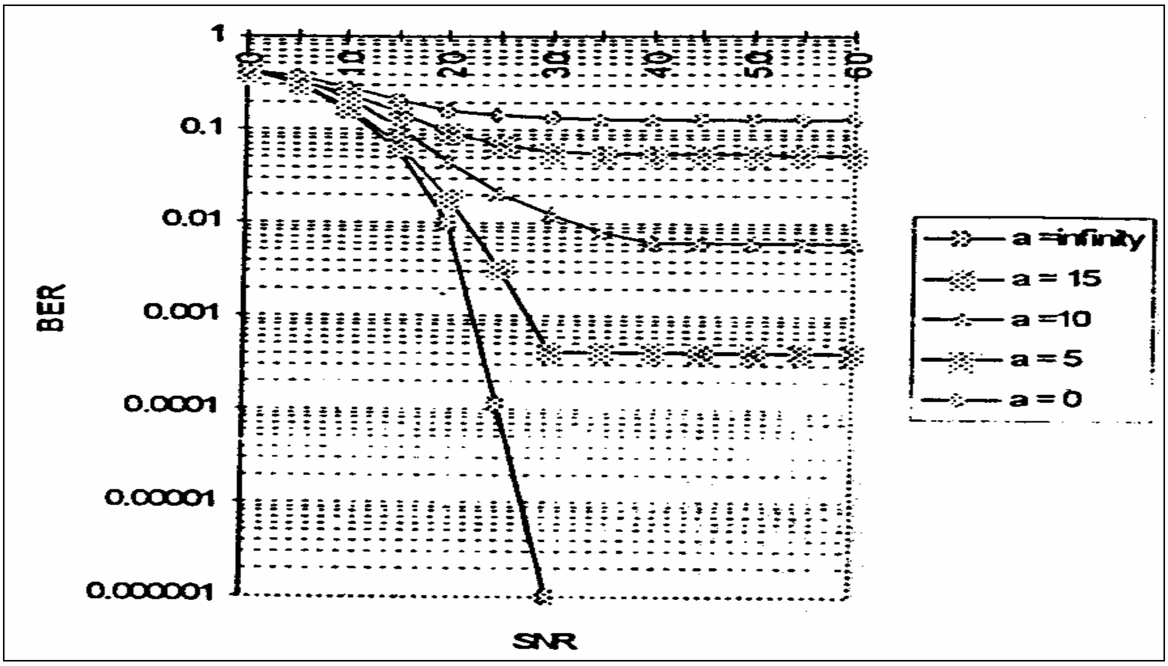

Fig. 11. Performance of OFDM DE 16 star QAM, single source per channel multiplexing in AWGN with Rician fading for various Rician power ratio, Doppler frequency *fd* = 0, 1 Hz.

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