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Performance Analysis of M-ary DPSK over VHF air-to-ground Communication Channel

Amr Aly Nagy , Gamal Mabrouk Abdel-Hamid, Ahmed E. Abdalla
Egyptian Armed Forces

Abstract:

This paper is concerned with evaluating the performance of M -ary differential phase shift keying (M-ary DPSK) modulation schemes over (very high frequency) VHF aeronautical channel (air-to-ground communication channel). The paper investigated the analytical bit error rate (BER) performance of binary differential phase shift keying (BDPSK) over aeronautical channel for flight scenarios: En-route, Arriving, Taxiing, and parking. By using the published measurement parameters, the analytical results are verified through modeling and computer simulation. The BER results show that multipath fading and Doppler shifts in the VHF aeronautical channel degrade the performance of M -ary DPSK modulation schemes over the channel. In order to combat fading and improve the BER performance of this channel, the paper proposed computer simulation of the performance of differential space time block coding (DSTBC) using two antennas at the transmitter and one antenna at the receiver.

Keywords:
Air-to-ground communication channel, En-route, Arriving, Taxi, parking, differential phase shift key (DPSK) and differential space time block coding (DSTBC)

1. Introduction:

The air-to-ground communications between an aircraft and ground radio site appears in many civilian and military applications such as the air traffic control (ATC) which is used for achieving a high efficient and safe air flights and also providing flight services [1]. The VHF digital link (118 MHz to 137 MHz) with 25 kHz channel spacing was divided into 760 channels and was assigned for both civilian and military air to ground communications [1,3]. A stochastic model for the air to ground channel is proposed in ref.[2]. This model describes the propagation between aircraft and ground terminal as multipath propagation which is a common problem in wireless communications as shown in figure 1. Multipath propagation occurs when there exist multiple propagation paths between the transmitter and receiver [4, 5]. These multiple propagation paths result from reflections and scattering of the propagating electromagnetic field by objects (mountains, Buildings,…etc.) in the propagation environment. The degrees to which these reflections distort the received signal depend on the number, the strength of the reflections which in turn is a function of the electric properties of the reflectors and scatterers, and the discrimination of the antenna gain pattern in the direction of the arriving reflections [5]. The aeronautical channel model divided the flight into four different scenarios: En-route, Arrival, Taxi and Parking.

Each of these scenarios has its own parameters which is characterizing the type of fading, Doppler, and delay. By comparing aeronautical channel with the traditional terrestrial mobile radio channels, air-to-ground channels not only suffer from multipath fading which is less effective on angle modulation signals than linear modulation signals but also suffer from large Doppler spread that can complicate the problem of estimating the channel accurately for coherent detection. For such channel (high-mobility environment) it may be difficult or costly to estimate the channel accurately [7], so received signals can be detected non-coherently using DPSK which can be demodulated without the use of channel estimates. Appropriate modulation schemes should be used, e.g., differential quadrature phase shift keying (DQPSK) used in military Link-11 and differential 8 phase shift keying (D8PSK) used in VHF data link (VDL) mode 2 [8]. Due to the poor BER performance of this communication system; there was necessary need to mitigate fading effects. Space time coding is one of many solutions of this problem. Some references analyzed the BER performance of different phase shift keying modulation schemes in aeronautical channel, one of them [8] compared between different coherent and non-coherent modulation schemes in the en-route scenario and concluded that the differential modulation schemes are more suitable for aeronautical channels due to its ability to reduce the complexity of the receiver and withstand the Doppler shift. Another reference [12] used finite-state Markov model for analyzing the performance of the four flight scenarios. The author in reference [6] utilized the frequency diversity to improve the performance of the aeronautical communications. The remainder of the paper is structured as follows: section 2 presents the aeronautical channel model. Single input single output (SISO) BER performance analysis of DPSK over air-to-ground communication channel is introduced in section 3. Unitary DSTBC BER performance analysis over air-to-ground communication channel presented in section 4. Finally, section 5 gives some concluding remarks.

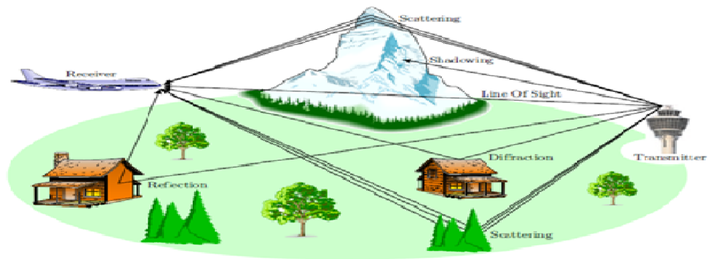


Figure (1): *Multipath propagation in air-to-ground communications systems [6]*

2. Aeronautical Channel Model

The aircraft during the flight subjected to different conditions leads to different channel scenarios. These scenarios are characterized by the type of fading , the Doppler, and the delays in the system. The flight divided into four scenarios [9]: En-route scenario, Arrival and takeoff scenario, Taxi scenario, and Parking scenario.

A. En-route scenario

The en-route scenario is applied when the aircraft is airborne and commun icates with the ground site as shown in figure 2.

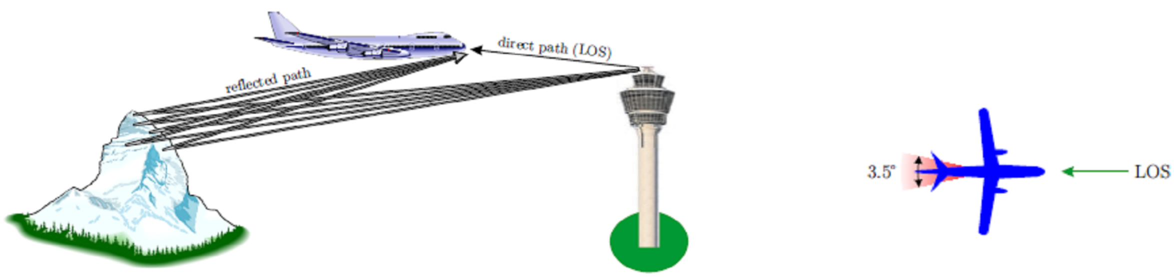


Figure (2): *Multipath propagation for en-route scenario [6]*

As shown in figure 2 the multipath channel consists of a LOS path as well as a cluster of reflected, delayed paths. Therefore, this scenario ma y be characterized by Rician fading with rice factor k=[2 – 20] dB [2].

$$K = \frac{a^2}{c^2} \tag{1}$$

Where K is the relation between the power of the LOS component a^2 and the average power of the scattered component C^2 [2]. when K is large (greater than 20 dB), the channel is well approximated by an Additive White Gaussian Noise (AWGN) channel and when K is small (smaller than -20 dB) the channel is well approximated by the Rayleigh fading channel [5]. The speed of the aircraft assumed to be 440 m/s so this scenario is characterized by fast fading due to the resulting Doppler spread

$$f_d = \frac{v}{\lambda} \cos\theta \tag{2}$$

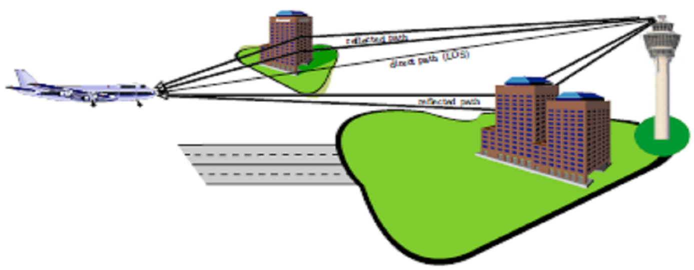
Where v is the relative speed between the transmitter and receiver (aircraft speed) ,λ carrier wave length and θ angle of arrival (AOA) of the received signal.
As shown in figure 2 assuming the direction of the LOS path coincides with the heading of the aircraft resulting in a carrier shift of the LOS path by f_{Dmax} (maximum Doppler spread), whereas the scattered components come from behind. The scatterers assumed to be uniformly distributed within beamwidth of diffuses component with $\beta=3.5^o$, i.e. the angles of arrival have a small range [$\pi-\beta/2$, $\pi+\beta/2$] that's due to high altitude (assume 10Km) of the aircraft. The Doppler spread f_d is a random variable with probability density function (pdf) known as Jakes distribution with maximum value =200 Hz at 137 MHz carrier frequency f_c [2].

$$p_{f_D}(f_D) = \begin{cases} \dfrac{1}{\pi f_{D_{max}} \sqrt{1-\left(\dfrac{f_D}{f_{D_{max}}}\right)^2}}, & if\ |f_D| < f_{D_{max}} \\ 0, & else \end{cases} \tag{3}$$

The maximum delay spread $\tau_{max} = 33\mu s ; \tau = \frac{\Delta d}{c}$ and $\Delta d \approx h(\text{aircraft altitude})$ [2].

B. Arrival and takeoff scenario

The arrival and takeoff scenario is applied when the aircraft is about to land (or increase its speed and altitude to go en-route) and communicates with the ground site as shown in shown Figure 3.



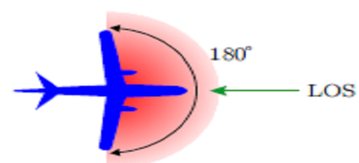


Figure (3): *Multipath propagation for arrival scenario [6]*

It can be assumed that the LOS path is present during this scenario while the aircraft is still airborne. On the other hand, also there will be scattered path components, mainly from buildings at the airport itself. The result is again a Rician channel k_{rice} =[9-20] dB [2]. The aircraft speed during the arrival assumed to be V =25:150 m/s so this scenario is characterized by Rician fast fading. The beam width of scattered components is $\beta=180^o$; the scattered components is broader than in the en-route environment. Since the aircraft is still some distance away from the airport and maximum excess delays $\tau_m \approx 7\mu s$ [2].

C. Taxi scenario

The taxi scenario is applied when the aircraft is on the ground and travelling toward or from the terminal, as shown in following Figure 4.

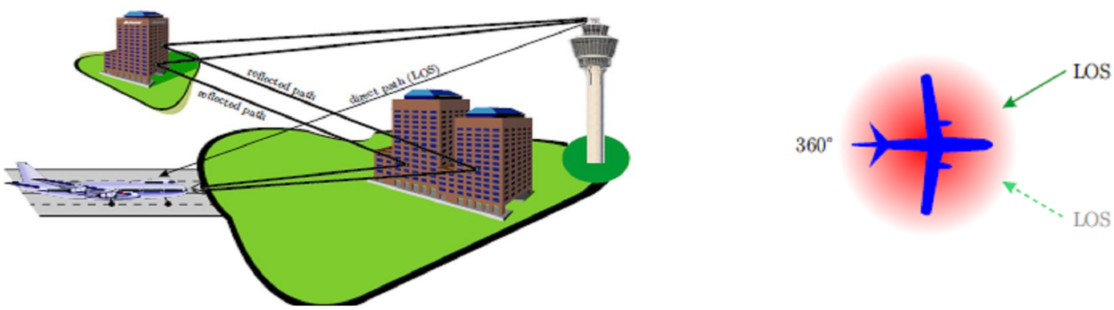


Figure (4): *Multipath propagation for taxi scenario [6]*

This scenario is characterized by Rician fading. The aircraft speeds V=0...15 m/s during taxi. The beam width of the scattered components is $\beta=360^{o}$ and K_{rice} ≈6.9 dB. The maximum excess delays $\tau_m \approx 0.7$ µs.

D. Parking scenario

The parking scenario is applied when the aircraft is on the ground and travelling at very slow speed close to the terminal or is parked at the terminal, as shown in following figure 5.

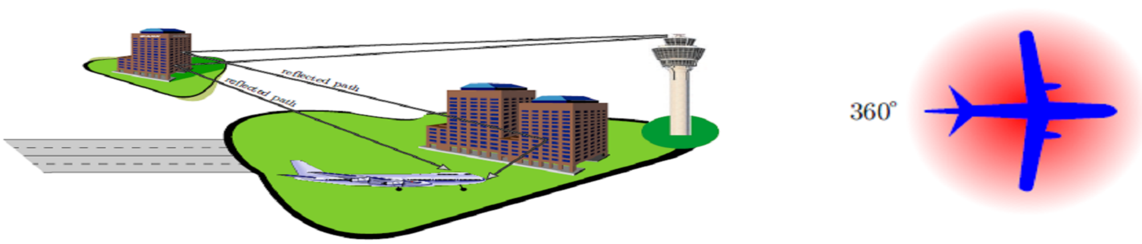


Figure (5): *Multipath propagation for parking scenario [6]*

The LOS path is assumed to be blocked in this scenario, which results in Rayleigh fading. Although the airport control tower should always be installed in a place where there is a line of sight to all aircrafts during taxiing or parking but due to the high density at airports, that is not always possible. Due to the fact that the aircraft is parked at the terminal or travelling at very slow speed, the fading is even slower than in the taxi scenario V= 0..5m/s, the beam width of the scattered components is $\beta=360^{o}$, K_{rice} =0 dB. The maximum excess delays $\tau_m \approx 0.7$ µs.

3. Single input single output (SISO) BER performance analysis:

A. Numerical analysis

When using a binary DPSK modulation scheme for transmitting information bits over a channel that characterized by both fast Rician fading and AWGN.
The input information bits are differentially encoded, resulting in the transmitted bit

$$\nu_k = \nu_{k-1} x_k \tag{4}$$

Where ν_k is the current transmitted bit and x_k is the current information bit
After passing through the fast-fading channel, the received information bit ω_k in the k^{th} transmission interval is

$$\omega_k = G_k \nu_k + N_k \tag{5}$$

Where G_k is the complex Gaussian fading amplitude associated with the k^{th} received bit
N_k is a zero mean complex Gaussian noise random variable.
For the a Rician channel α_k is the magnitude of G_k, namely, $\alpha_k \triangleq |G_k|$, has PDF

$$p(\alpha_k) = \alpha_k \frac{2(1+K)}{\Omega} \exp(-K - \frac{\alpha_k{}^2(1+K)}{\Omega}) I_0 \left(2\alpha_k \sqrt{\frac{K(1+K)}{\Omega}}\right) \tag{6}$$

Where: $\Omega = E\{\alpha_k^2\} = 2\sigma^2(1+K)$ From ref.[10,11] ,the average BEP for DPSK in the fast fading (aeronautical channel) in case of Rician fading

$$\overline{P_b} = \frac{1}{2}\left[\frac{1+K+\overline{\gamma_b}(1-\rho_c)}{1+K+\overline{\gamma_b}}\right] \exp\left(-\frac{K\overline{\gamma_b}}{1+K+\overline{\gamma_b}}\right) \tag{7}$$

Where: γ_b is the average signal to noise ratio ρ_c is the channel correlation coefficient after a bit time T_b. The channel correlation coefficient is thus ρ_c evaluated at $T = T_b$ for BDPSK. Assuming the uniform scattering model $\rho_c = j_0(2\pi f_d T_b)$ [11].
In case of Rayleigh fading ($K = 0$) this simplifies to

$$\overline{P_b} - \frac{1}{2}\left[\frac{1+\overline{\gamma_b}(1-\rho_c)}{1+\overline{\gamma_b}}\right] \tag{8}$$

B. Simulation model

As shown in the following block diagram, figure 6. The first step is to initiate random steam, then modulate them by using M-ary DPSK modulator and the modulated signal passes through the channel model which acts like a filter, then applying the effect of the AWGN on the output of the channel, finally demodulate the signal and calculate the BER by comparing the output of the demodulator and the original data stream.

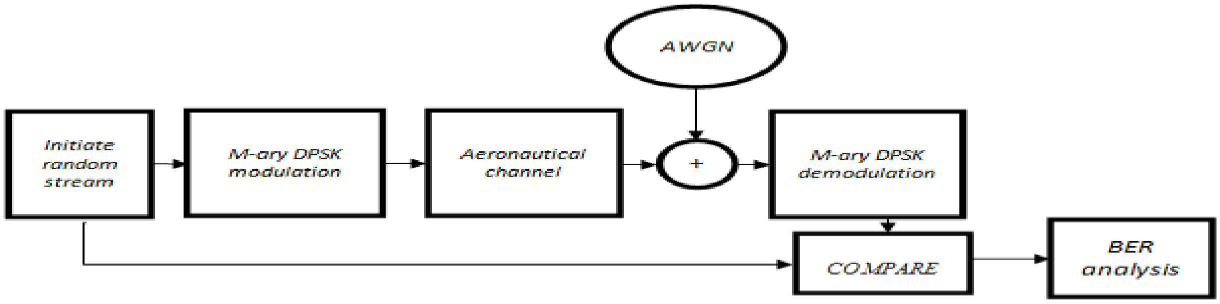
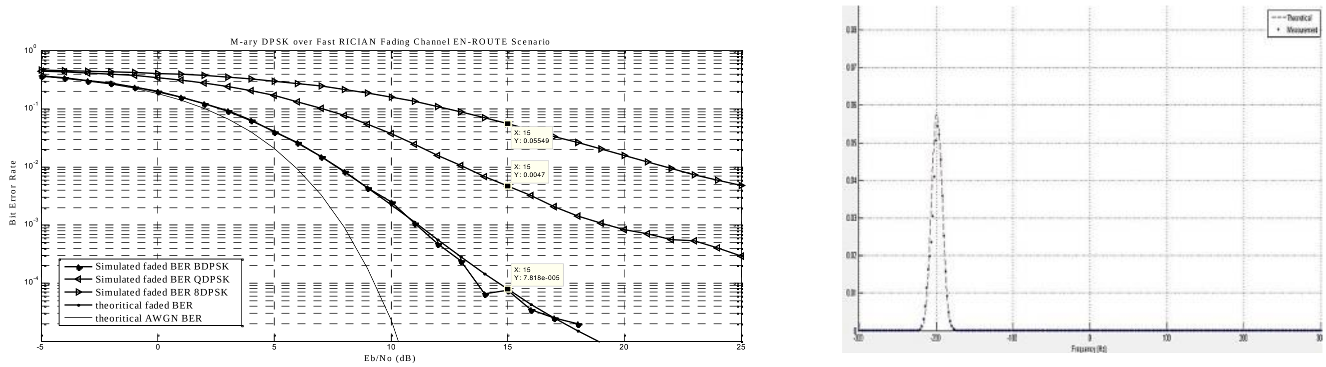


Figure (6): *Block diagram of the simulation*

C. Simulation results

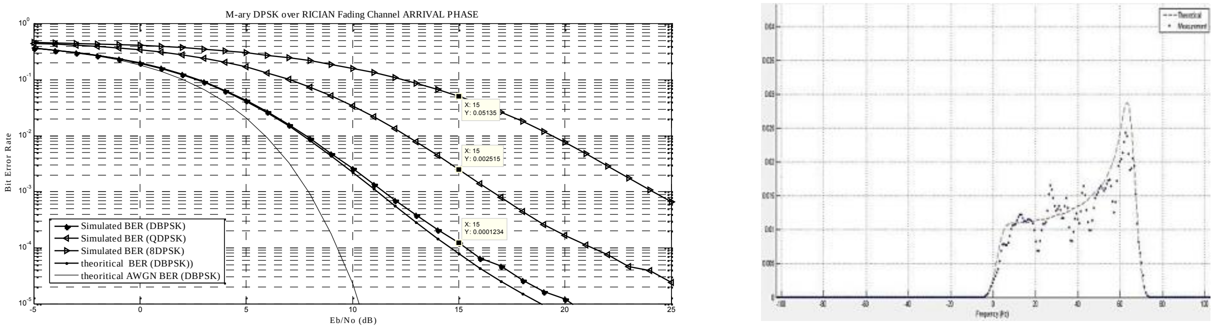
The following figures show the simulation results of the four scenarios over aeronautical channel.



(a) (b)

Figure (7): *(a) Performance of M-ary DPSK over the aeronautical communication channel (En-route scenario) K_{rice}=10dB, f_dT_b=.02 (b) Doppler power spectrum*

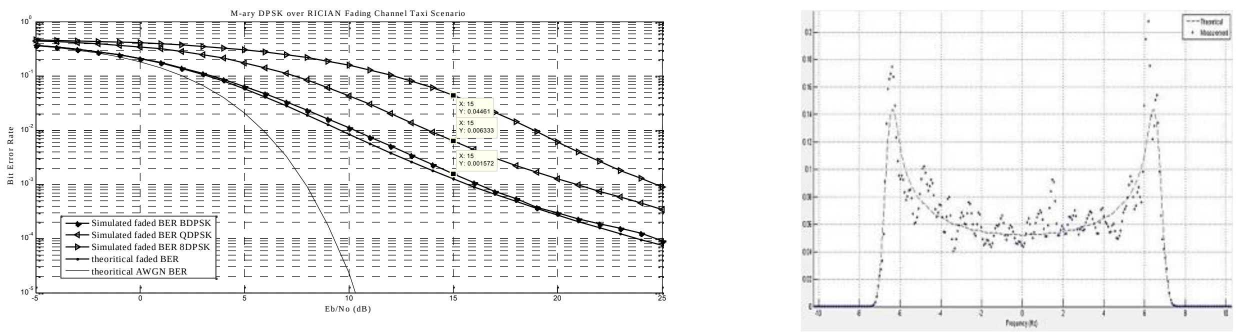
Figure 7-a shows the simulated BER performance versus SNR of (M-ary DPSK) 2, 4 and 8 DPSK over the en-route scenario assuming K_{rice} =10 dB, the aircraft speed as 440 m/s and bit rate of 10.5 Kb/s resulting in $f_d.T_b$ (Doppler spread*data rate ratio) to be about 0.02, the curve representing BDPSK is verified by the theoretical curve. As shown in figure when E_b/N_o =15dB, BER (8DPSK) =.05, BER (QDPSK) =.0047, and BER (BDPSK) =$7*10^{-5}$. The performance of BDPSK modulation scheme is better than the performance of the other schemes, but the bandwidth effecicieny of BDPSK is less than them. Figure 7-b shows the simulated Doppler power spectrum characterizing the channel (en-route scenario) equivalent to diffuses components beamwidth =3.5º.



(a) (b)

Figure (8): *(a) Performance of M-ary DPSK over the aeronautical communication channel (Arrival scenario) K_{rice}=10dB, $f_d T_b$ =.0068, (b) Doppler power spectrum*.

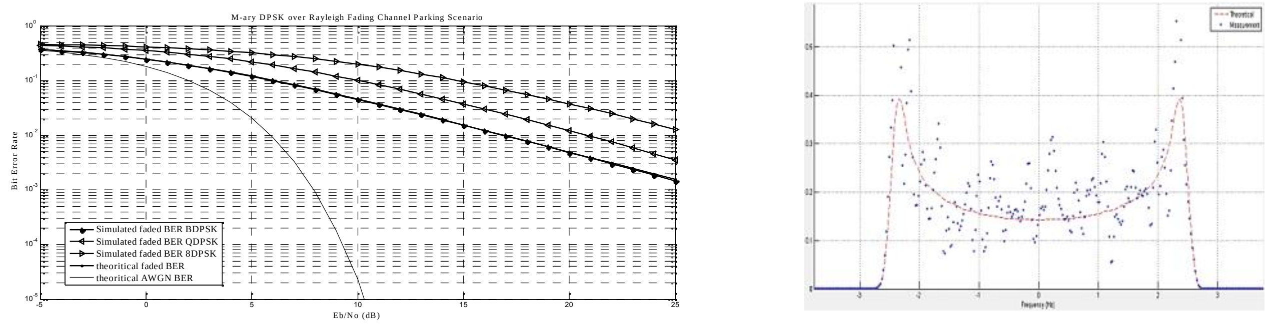
Figure 8-a shows the simulated BER versus SNR over the arrival scenario assumin g K_{rice} =10 dB, the aircraft speed as 150 m/s and bit rate of 10.5 Kb/s resulting in $f_d.T_b$ to be about 0.0068. As shown in figure E_b/N_o =15dB achieved BER (8DPSK) =.05, BER (QDPSK) =.0025, and BER (BDPSK) =1.2*10^{-4}. Figure 7-b shows the simulated Doppler power spectrum characterizing the channel (arrival scenario) equivalent to diffuses components beamwidth =180º.



(a) (b)

Figure (9): *(a) performance of M-ary DPSK over the aeronautical communication channel (Taxi scenario) K_{rice}=6.9dB, $f_d T_b$ =.0006, (b) Doppler power spectrum*

Figure 9-a shows the simulated BER versus SNR over the taxi scenario assuming K_{rice} =6.9 dB, the aircraft speed as 15m/s and bit rate of 10.5 Kb/s resulting in $f_d.T_b$ to be about 0.0006. As shown in figure E_b/N_o =6.9dB achieved BER (8DPSK) =.045, BER (QDPSK) =.0063, and BER (BDPSK) =1.5*10^{-3}. Figure 7-b shows the simulated Doppler power spectrum characterizing the channel (taxi scenari o) equivalent to diffuses components beamwidth =360º.



(a) (b)

Figure (10): *(a) performance of M-ary DPSK over the aeronautical communication channel (Parking scenario) Krice=0dB, $f_d T_b$ =.0002, (b) Doppler power spectrum*

Figure 10-a shows the simulated BER versus SNR over the parking scenario assuming K_{rice} =0 dB, the aircraft speed as 5m/s and bit rate of 10.5 Kb/s resulting in $f_d.T_b$ to be about 0.0002. When E_b/N_o =15dB, BER (8DPSK) =.096, BER (QDPSK) =.038, and BER (BDPSK) =$1.5*10^{-3}$. Figure 7-b shows the simulated Doppler power spectrum characterizing the channel (taxi scenario) equivalent to diffuses components beamwidth =360°.

4. Unitary DSTBC BER performance analysis

A. Simulation details

This scheme is based mainly on Alamouti scheme [13] which considered as multi-input-single-output (MISO) communication system with two transmit antennas and one receive antenna, but DSTC scheme can demodulate and decode the received signal without channel estimation at the receiver [7].

Tarokh and Jafarkhani presented a differential detection scheme for Alamouti 's code[14]. The DSTBC scheme can be described as follows: Two information symbols x_1 and x_2 are buffered by the transmitter and transmitted in two time slots in the following manner. In the first time slot, symbol x_1 is transmitted over the first antenna and simultaneously symbol x_2 is transmitted over the second antenna. In the second time slot, signal $-x^*_2$ is transmitted by the first antenna and x^*_1 is transmitted by the second antenna.

In general, an STBC encodes K complex symbols $x_1,...,x_K$ by including linear combinations of $\pm x_1,\dots, \pm x_K$ and their conjugates $\pm x^*_1,\dots, \pm x^*_K$ in the code matrix. This can be expressed in a following form as

$$V \equiv \frac{1}{\sqrt{2}} \sum_{i=1}^{2} A_i x_i + B_i x_i^* \qquad (9)$$

Where A_i and B_i {i=1,2} are known as dispersion matrices since they disperse the symbols over the transmit antennas. $\frac{1}{\sqrt{2}}$ is a normalization factor used to make the total transmitted power from the two antennas at one time slot to be one [7].

The dispersion matrices are :

$$A_1 = \begin{bmatrix}1 & 0\\0 & 0\end{bmatrix},\ B_1 = \begin{bmatrix}0 & 0\\0 & 1\end{bmatrix},\ A_2 = \begin{bmatrix}0 & 1\\0 & 0\end{bmatrix},\ B_2 = \begin{bmatrix}0 & -1\\0 & 0\end{bmatrix} \quad (10)$$

i.e. the first code matrix can be written as

$$v_1 = \frac{1}{\sqrt{2}}\begin{bmatrix}x_1 & x_2\\-x_2^* & x_1^*\end{bmatrix} \quad (11)$$

Then these code matrices were differentially encoded to construct the transmitted matrices as follows:

$$s_t = v_t\, s_{t-1} \quad (12)$$

Where s_t is the transmitted matrix at time t, v_t is the code matrix at time t

After passing through the cannel the received matrices can be represented as:

$$Y_t = H\, S_t + N_t \quad (13)$$

Where Y_t is the received matrix at time t, H is 2x1 channel matrix and N_t is 2x1 noise matrix representing separate AWGN to each path.

Finally maximum likelihood (ML) differential decoding is given by [7]

$$\hat{v}_t = \arg\max_{l\in Q}\left\|y_{t-1} + y_t v_l^H\right\| \quad (14)$$

Where Q={0,1,2,3}, and $\|\cdot\|$ denotes the frobenius norm of a matrix

The following block diagram represents the differential STBC scheme over 2x1 communication systems.

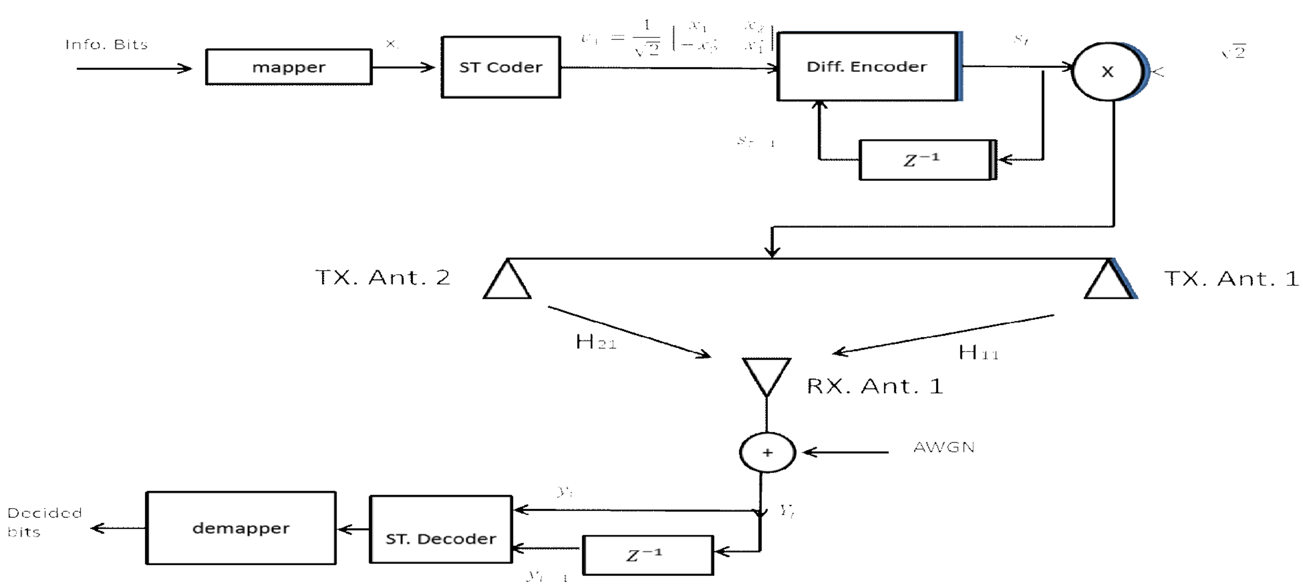


Figure (11): *Block diagram showing the differential transmission of an STBC scheme over an 2X1 communication system.*

B. Simulation results

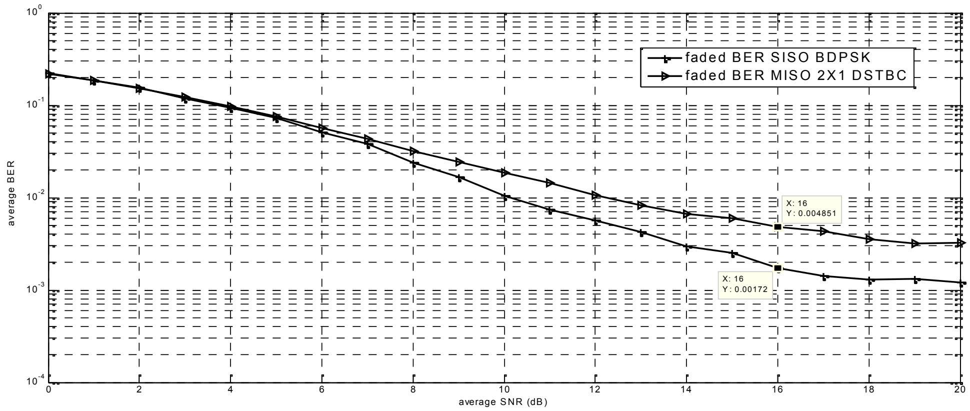


Figure (12): *Performance of DSTBC 2X1 ,DBPSK over the aeronautical communication channel (En-route scenario)*

Figure (12) representing the performance of both DSTBC 2X1 and DBPSK in en_route scenario assuming Krice=5dB, fdTb=.02 , When Eb/No =16 dB, BER (DSTBC) =.0049, BER (DBPSK) =.0017

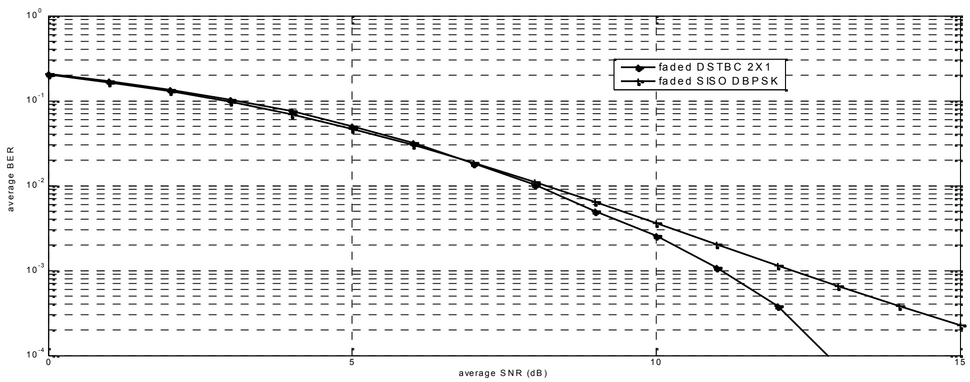


Figure (13): *Performance of DSTBC 2X1,DBPSK over the aeronautical communication channel (Arrival scenario)*

Figure (13) representing the performance of both DSTBC 2X1 and DBPSK in arrival scenario assuming Krice=9dB, fdTb =.0068, When Eb/No =12 dB, BER (DSTBC) =.00038, BER (DBPSK) =.0011

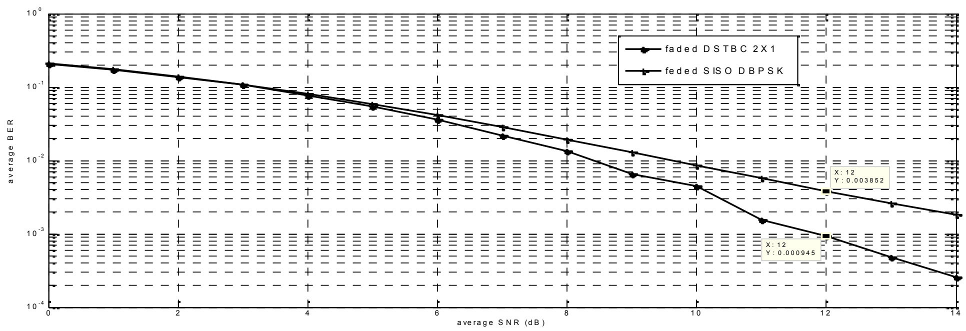


Figure (14): *performance of DSTBC 2X1,DBPSK over the aeronautical communication channel (Taxi scenario)*

Figure (14) representing the performance of both DSTBC 2X1 and DBPSK in taxi scenario assuming Krice=6.9dB, fdTb =.0006, When Eb/No =12 dB, BER (DSTBC) =.00094, BER (DBPSK) =.0038

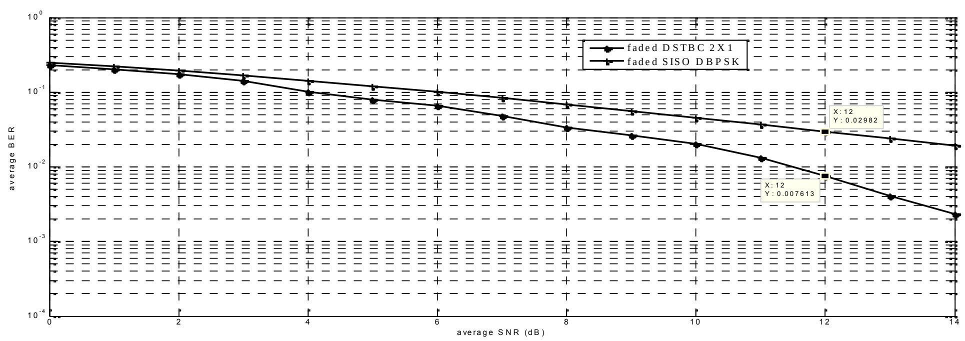


Figure (15): *performance of DSTBC 2X1,DBPSK over the aeronautical communication channel (Parking scenario)*

Figure (15) representing the performance of both DSTBC 2X1 and DBPSK in parking scenario assuming Krice=0dB, fdTb =.0002, When Eb/No =12 dB, BER (DSTBC) =.0076, BER (DBPSK) =.03

Figures (12, 13, 14, 15) are representing the performances of the DSTBC 2X1 of the different flight scenarios in the worst conditions (maximum speed, minimum Krice factor and maximum delay spread). As shown in these figures the performances were enhanced due to using DSTBC. In future work, the performances of using higher diversity order will be investigated.

5. Conclusions

This paper has discussed the different scenarios of the aircraft flight (En-route, Arrival, Taxi, and Parking), the behavior of the air-to-ground communication channel was introduced at each of these scenarios, and also the BER performance of different phase shift keying (M-ary DPSK) modulation schemes over this channel (VHF aeronautical channel) is proposed through computer simu lation. This performance is approved by analytical closed form for DBPSK modulation scheme. The BER results show that multipath fading and Doppler shifts in the air -to-ground communication channel degrade the probability of error. In order to combat fading and improve the BER performance of this channel, the paper proposed computer simulation of the performance of differential space time block coding (DSTBC) using two antennas at the transmitter and one antenna at the receiver.

References

[1] S. Elnoubi, "A simplified stochastic model for the aeronautical mobile radio channel," presented at the IEEE Vehicular technology conference, Denver, Colorado, May,1992.

[2] E. Haas, "Aeronautical channel modeling," IEEE transactions on Vehicular technology, vol. 51, March 2002.

[3] E.T.S.institute, "VHF air-ground digital link (VDL) mode 2 technical characteristics and methods of measurement for ground -based equipment," in part 1: physical layer and mac sub-layer, ed, 2010.

[4] J. G. Proakis, "digital communications". New York: McGraw -Hill, 1995.

[5] R.D.Michael Rice, K. Welling, "Narrowband channel model for aeronautical telemetry," IEEE transactions on Aerospace and electronic systems ,Oct. 2000.

[6] E. Haas, "Design, evaluation and implementation of a multi -carrier transmission system for aeronautical communications," phd thesis, Munich,Germany, Oct.2002.

[7] B. Vucetic, "space-time coding" West Sussex,England,John Wiley & sons lnc., 2003.

[8] G.Min, Z.Chao, H.Han, L.Xiaokang, "Performance analysis of different phase shift keying modulation schemes in aeronautical channels," Tsinghua science and technology, vol. 14, December 2009.

[9] P.Hoeher, E.Haas, "aeronautical channel modeling at VHF -band," IEEE Vehicular Technology Conference, 1999.

[10] M.K.Simon, M.S.Alouini "Digital communication over fading chan nels," Hoboken, New Jersey: John Wiley& sons inc., 2005.

[11] Andrea Goldsmith "wireless communications". Cambridge university press, 2005.

[12] Q. Pan , S.Liu, M.Xu, C.Jia, "Finite-State Markov Model for the Aeronautical Channel," IEEE Wireless Communications, Networking and Mobile Computing, Sept.2009.

[13] Siavash M. Alamouti, " A Simple Transmit Diversity Technique for Wireless Communications," IEEE JOURNAL on select areas in Communications, Oct. 1998

[14] Vahid Tarokh, Hamid Jafarkhani, " A Differential Detection Sche me for Transmit Diversity," IEEE JOURNAL on select areas in Communications, July. 1998