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MMSE Based Beamforming for Chip Interleaved CDMA in Aeronautical Mobile Radio Channel

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Abstract**—**This paper addresses the performance of antenna array beamforming on Chip-Interleaved Code Division Multiple Access (CI_CDMA) system based on Minimum Mean Square Error (MMSE) detector in aeronautical mobile radio channel. Multipath fading, Doppler shifts caused by the speed of the aircraft, and Multiple Access Interference (MAI) are the most important reasons that affect and reduce the performance of aeronautical system. In this paper we suggested the CI-CDMA with antenna array to combat this fading and improve the bit error rate (BER) performance. We further evaluate the performance of the proposed system in the four standard scenarios in aeronautical mobile radio channel.

Keywords**—**Aeronautical Channel, CI-CDMA, Beamforming.

I. Introduction

AERONAUTICAL communication system is one of the digital communication systems that require an assessment of their performance according to the operating environment. Like any digital communication systems, the received signal is suffering with the line of sight (LOS) to fading due to multiple paths constructive or deconstructive. Reflection, scattering, diffraction and shadowing during air flight of an aircraft are important reasons for this fading. It is characterized by the so-called large-scale models of multiple random channel spread by Doppler power spectrum and delay power spectrum, i.e., the scattering function $P_s(\tau, f_D)$. The Doppler spectrum is assumed to be independent from the delay spectrum $P_s(\tau, f_D) = P_s(\tau).P_s(f_D)$ [1]. The aeronautical mobile radio channel model divides the flight into four different scenarios: En-route, Arrival, Taxi and Parking. Each of these scenarios has its own parameters which characterize the type of fading, Doppler, and delay [1], [2].

Code Division Multiple Access found in aeronautical communications systems enable large number of aircraft to take advantage of them to achieve the simultaneous multi-user communication in the same channel at the same time and channel capacity [4]. As a result of the nature of the aeronautical channel, which is characterized by multipaths, the use of this system achieves the best performance to reduce the effect of interference from other users, but results in the emergence of MAI beside intersymbol interference (ISI). In order to solve such problems, CI-CDMA has been proposed by several research groups recently [5], [6].Unlike interleaver used in the coding sequence, interleaver in CI-CDMA does not scramble bits of information, but to spread the chips from a single code modulated in time. The influence on transmission performance of spreading code periods in simple CI-CDMA considers a set of bits at a time and combines bit-and-chip interleaving.CI-CDMA improves the performance of CDMA systems in Rayleigh fading channel addressed [7].

Array beamforming techniques have been widely used in wireless communication systems for many reasons. By flexible steering of beams and nulls, an array can enhance desired signals whereas the undesired signals such as interference and jammers are suppressed. Using MMSE based antenna beamforming in CDMA system can reduce the amount of co-channel interference from other users within the channel and its neighboring cells, thereby increasing the capacity of the system [8], [9].

In this paper we suggest that the CI-CDMA with antenna array to combats this fading and improves the bit error rate (BER) performance. We also evaluate the performance of the proposed system in the four standard scenarios in aeronautical channel model. This paper is organized as follows: Section II gives the aeronautical mobile radio channel model and discusses the four standard scenarios. Section III describes the proposed system model and the MMSE based beamforming technique. Section IV includes the simulation and results which are analyzed based on the BER performance. Finally, Section V contains the conclusions.

II. Aeronautical Channel Models

In the aeronautical mobile radio channel, different communication channel scenarios are created due to the aircraft exposure to different condition during the flight. These scenarios are characterized by Doppler, delay and type of fading. Division of the journey to four scenarios [1], [2] are shown in Fig. 1.

The en-route scenario is applied when the aircraft is airborne and ground works in the air or atmospheric air communication. Ground-air communication is considered to be the link between a base station on the ground and an aircraft.

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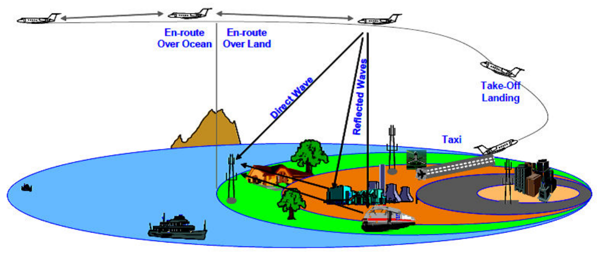

Fig. 1 Aeronautical Channel Scenarios

Air-air communication is considered to be the link between two airborne aircrafts. The aircraft receives multipath signals consisting of a LOS path and a cluster of reflected, delayed paths [1]. Therefore, this scenario may be characterized by Rician fading with rice factor $K = [2 - 20]$dB. The speed of the aircraft takes value from the range $17{:}\,440$ m/salso this scenario is characterized by fast fading due to the resulting Doppler spread. The scatterers assumed to be uniformly distributed within beam width 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 is due to high altitude (assume10Km) of the aircraft [1]. The Doppler spread 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], [3].

The arrival and takeoff scenario is applied when the aircraft is about to land and communicates with the ground site [1].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 $K = [9 - 20]$dB [2], [3]. 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 [1]. Since the aircraft is still some distance away from the airport and maximum delay $\tau max \approx 7\mu s$ [2].

The taxi scenario is applied when the aircraft is on the ground and travelling toward or from the terminal [1]. This scenario is characterized by Rician fading. The aircraft speeds $V = 0 \ldots 15$ m/s during taxi. The beam width of the scattered components is $\beta = 360^o$and Krice ≈ 6.9 dB. The maximum excess delays $\tau \approx 0.7$ µs [2].

The parking scenario is applied when the aircraft is on the ground and travelling at very slow speed close to the terminal [1]. The LOS path is assumed to be blocked in this scenario, which results in Rayleigh fading. During taxing and parking, a line of sight between all aircraft with airport control tower is not possible due to the high density airports. 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 $V = 0..5$m/s, the beam width of the scattered components is $\beta = 360^o$, Krice $= 0$ dB. The maximum delay $\tau \approx 0.7$ µs [1], [2].

To complete the list of possible aeronautical scenarios, Table I gives a set of parameters for the typical values that are proposed for simulations.

TABLE I
SUMMARY OF CHANNEL PARAMETERS [1]

	PARKING SCENRIO	TAXI SCENARIO	ARRIVAL SCENARIO	EN-ROUTE SCENARIO
Aircraft Velocity v $[\frac{m}{s}]$	5.5 0 …… 5.5	15 0 ….. 15	150 25 … 150	440 17 … 440
Maximum Delay τ_{max} [s]	7 µ sec	0.7 µ sec	7 µ sec	33 µ sec (66 µ sec) 6 µ sec ... 200 µ sec
Number of echo paths N	20	20	20	20
Rice Factor K_{Rice} [dB]	--	6.9	15 9 … 20	15 2 … 20
f_{DLOS}/f_{Dmax} factor	--	0.7	1	1
Start Angle φ_{aL} of Beam	0	0	-90	178.25
Start Angle φ_{aH} of Beam	360	360	+90	181.75
Exponential or two ray delay	exp	exp	exp	Two-ray
Slope time τ_{slope} [s]	1 µ sec	1/9.2 µ sec	1 µ sec	–

III. SYSTEM MODEL

In the proposed system, the bit sequence of the k^{th} aircraft is $b_k = [b_k(1), b_k(2), \ldots, b_k(\mathrm{L})]^T$, where $b_k(l) \in \{\pm 1\}$, L is the bit length. Then $b_k(n)$is interleaved by chip interleaver $\pi_k$to from $\acute{b}_k(i)$. The output form interleaver $\acute{b}_k(i)$ is spreaded by spreading code $c_k(i)$ to form the spreaded signal $m_k(i)$ of aircraft k, where $c_k(i) = [c_{k,0}(i), \ldots, c_{k,N_s}(i)]$, $c_k(i)$isthe bit index i.The spreaded bits $m_k(i)$are modulated by BPSK to form the transmitted signal $s_k(i)$. The system model for CI-CDMA transmitter is shown in Fig. 2.

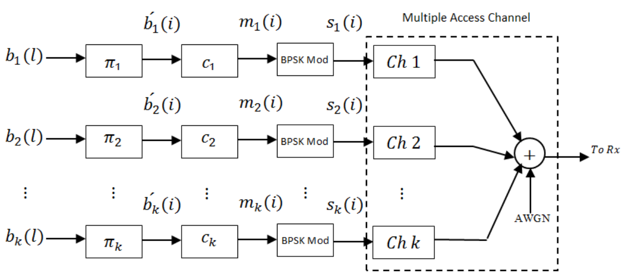

Fig. 2 CI-CDMA Transmitter

We assume that there are K aircraft in the CI-CDMA system, where the base station employs one N_A-element array. The proposed MMSE based beamforming receiver is shown in Fig. 3.

The output signal from adaptive beamformer can be given as:

$$r = \sum_{n=0}^{N_A-1} \omega_n^* x_n = w^H X \quad (1)$$

where, ω represents length N_A vector weights,x_n represents the length received signal, and the subscript ^{H} represents the Hermitian of a vector. i.e. $\omega^H = [\omega_o^*, \omega_1^*, \dots, \omega_{N_A-1}^*]$. The received signal arriving form direction θ the received signal is $x(\theta) = s(\theta)$ therefore the output signal is

$$r = \omega^H s(\theta) \quad (2)$$

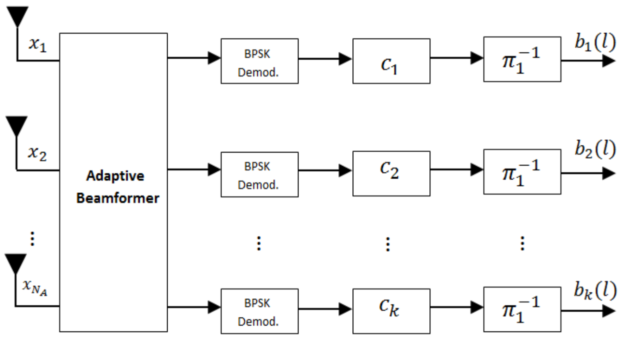

Fig. 3 CI-CDMA Receiver with antenna array

The antenna array of K receives message signal from $K+1$ aircraft. The received signal at each element is corrupted by thermal noise modeled as additive white Gaussian noise (AWGN), and multipath signal generated form aeronautical channel. The signal received is a sum over the signals from multiple users, one of which we will designate the "desired" signal. The received data is a sum of signal, interference and AWGN

$$x = \alpha h_o + n \quad (3)$$

$$n = \sum_{k=1}^{K} \alpha_k h_k + noise \quad (4)$$

The goal of the beamformation or interference cancellation is to isolate the desired signal to the use, contained in the term α_m, from the interference and noise. The vectors h_k are the spatial signatures of the k^{th}aircraft. Note that, unlike in direction of arrival estimation, we are not making any assumptions as to the structure of this spatial signature. However, in more realistic setting, this vector is a single realization of a random fading process.

The minimum mean squared error (MMSE) algorithm minimizes the error with respect to a reference signal d(t). In this model, the desired user is assumed to transmit this reference signal, i.e. $\alpha = \beta d(t)$, where β is the signal amplitude and d(t) is known to the receiving base station. The output y(t) is required to track this reference signal. The MMSE finds the weights ω that minimize theaverage power in the error signal, the difference between the reference signal and the output signal obtained using equation.

$$\omega_{MMSE} = \arg\min E[|e(t)|^2] \quad (5)$$

$$E[|e(t)|^2] = E[|d_k - w^H x_k|^2] \quad (6)$$

$$E[|e(t)|^2] = E\left[\left|d_k^2 - 2d_k w^H x_k + w^H x_k x_k{}^H w\right|\right] \quad (7)$$

$$E[|e(t)|^2] = d_k^2 - 2w^H E[d_k x_k] + w^H E[x_k x_k{}^H] w \quad (8)$$

where $E[d_k x_k]$ and $E[x_k x_k{}^H]$ in (8) are the cross correlation $r_{xd}$and the covariance matrix R_{xx} respectively then we can rewrite the equation

$$E[|e(t)|^2] = d_k^2 - 2w^H r_{xd} + w^H R_{xx} w \quad (9)$$

In order to minimize the cost function (9) with respect to the weights, one must compute the gradient, which achieved by the following equation:

$$\frac{\partial E\{|e(t)|^2\}}{\partial \omega^H} = R_{xx}^{-1} w - r_{xd} = 0 \quad (10)$$

Then, the optimum weights for MMSE detector is given by:

$$\omega_{MMSE} = R^{-1} r_{xd} \quad (11)$$

IV. Simulation and Results

In this section, the performances of MMSE based beamforming for CI-CDMA is adopted with the carrier frequency 118MHz and spreading code length 8.

A four user CI-CDMA system with MMSE based beamforming receiver described above was simulated. The channels considered in Section II were used for this simulation. The simulation parameters used in the paper are: the spreading length is 8 bits, the data length is 1024 bits and the interleaver index length is given by(8×1024) index. The simulation parameters are defined for all scenarios.

Figs. 4 and 5 show the BER vs. EbNo for En-route scenario with MMSE based beamforming receiver. These figures show the BER enhancement as increasing number of antenna elements. As shown in figures, the improvement by using 2 elements and 5 elements at $BER = 10^{-4}$is about 6 dB in case of $(k = 2dB)$ and is about 3 dB in case of $(k = 10dB)$.

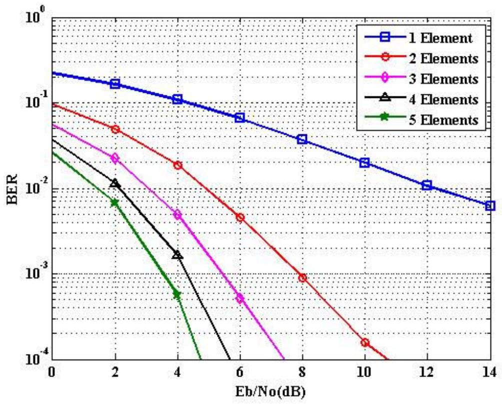

Fig. 4 En-Route Scenario, $(k = 2dB)$

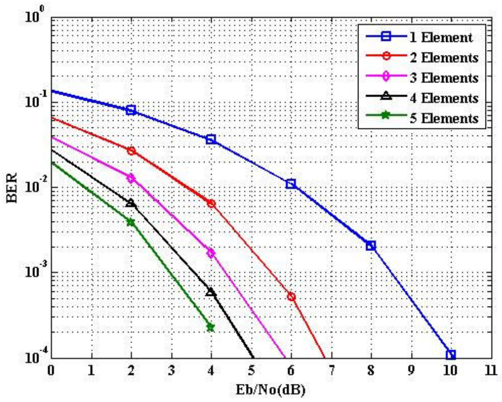

Fig. 5 En-Route Scenario $(\mathrm{k} = 10\mathrm{dB})$

Fig. 6 shows that the BER vs. EbNo for Arrival scenario with MMSE based beamforming receiver. This figure shows the BER enhancement as increasing number of antenna elements. As shown in figure, the improvement by using one element and 5 elements at $BER = 10^{-4}$is about 8 dB in case of $(k = 2dB)$.

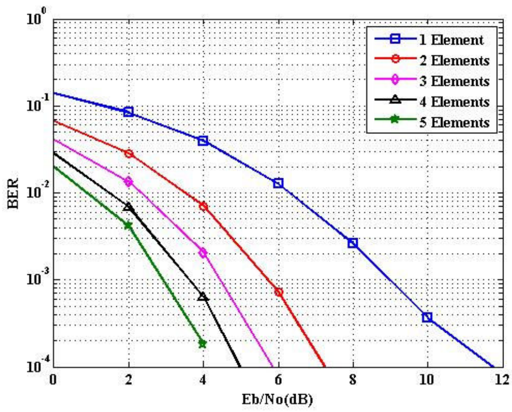

Fig. 6 Arrival Scenario, $(\mathrm{k} = 9\mathrm{dB})$

Fig. 7 shows that the BER vs. EbNo for Taxi scenario with MMSE based beamforming receiver. This figure shows the BER enhancement as increasing number of antenna elements. As shown in figure, the improvement by using 2 elements and 5 elements at $\mathrm{BER} = 10^{-4}$ is about 4 dB in case of $(\mathrm{k} = 6.9\mathrm{dB})$.

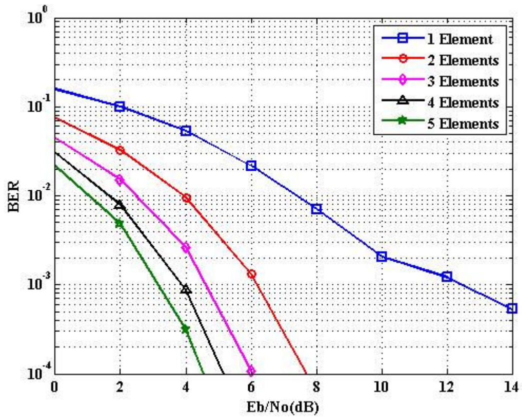

Fig. 7 Taxi Scenario$(\mathrm{k} = 6.9\mathrm{dB})$

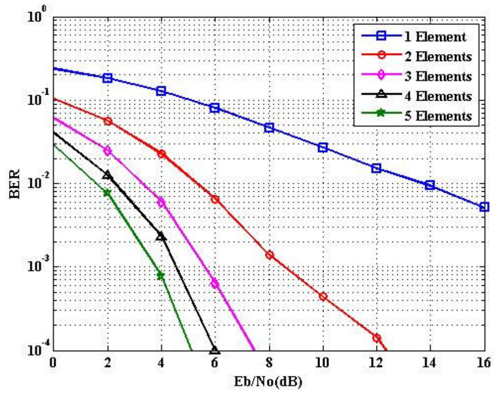

Fig. 8 Parking Scenario, $(\mathrm{k} = 0\mathrm{dB})$

Fig. 8 shows that the BER vs. EbNo for parking scenario with MMSE based beamforming receiver. This figure shows the BER enhancement as increasing number of antenna elements. As shown in figure, the improvement by using 2 elements and 5 elements at $\mathrm{BER} = 10^{-4}$ is about 8 dB in case of $(\mathrm{k} = 0\mathrm{dB})$.

V. CONCLUSION

In this paper, we propose MMSE based beamforming for CI-CDMA in aeronautical mobile radio channel. The BER performance of the proposed technique is compared to the system without beamforming under different channel scenarios. It has results shows that, the proposed scheme mitigates the effects of both MAI and ISI and provides better performance with low complexity. The proposed scheme can be improved by using the Multi Input Multi Output (MIMO) system with Chip by Chip iterative receiver principle.

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REFERENCES

[1] E. Haas, "Aeronautical channel modeling," Vehicular Technology, IEEE Transactions on, vol. 51, pp. 254-264, 2002.
[2] Amr. A. Nagy, Gamal. M. Abdel-Hamid and Ahmed E., "Performance analysis of DSTBC over VHF Air-to-Ground Communication Channels", International Journal of Computer Applications, vol.61, pp.34-38, January 2013.
[3] M. Rice, R. Dye, and K. Welling, "Narrowband channel model for aeronautical telemetry," Aerospace and Electronic Systems, IEEE Transactions on, vol. 36, pp. 1371-1376, 2000.
[4] David W. Matolak, "CDMA for communications in the Aeronautical Environment," IEEE Digital Avionics Systems Conference, Oct. 1997.
[5] R. H. Mahadevappa and J. G. Proakis, "Chip-Interleaved Block-Spread Code Division Multiple Access," IEEE Trans. Communications, vol. 50, no. 2, pp.235–247, Feb. 2002.
[6] R. H. Mahadevappa and J. G. Proakis, “Mitigating multiple access interference and intersymbol interference in uncoded CDMA systems with chip-level interleaving,” IEEE Trans. Wireless Comm., vol. 1, pp.781–792, Oct. 2002.
[7] Y. Lin and D. W. Lin, "Chip interleaving for performance improvement of coded DS-CDMA systems in Rayleigh fading channels," IEEE 58th Vehicular Technology Conference, 2003.
[8] S. Choi, J. Choi, H.-J. Im, and B. Choi, “A novel adaptive beamforming algorithm for antenna array CDMA systems with strong interferers,” IEEE Trans. Veh. Technol., vol. 51, no. 5, pp. 808–816, Sept. 2002.
[9] C. K, Rahulamathavan, Y., Lambotharan, S & Ding, Z , "MMSE-based beamforming techniques for relay broadcast channels,". IEEE Transactions on Vehicular Technology, pp. 4045-4051, Oct. 2013.