Improving the Forward Link of the Future Airport Data Link by Space-Time Coding

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***Abstract*—In the context of the future communication system for the airport surface operations (AeroMACS), we investigate the 2×1 Alamouti scheme applied to the 802.16e standard for improving the performance of the forward link. We propose a novel space-time coding realization which preserves the original frame structure of WiMAX, analyzing its performance in a realistic airport environment. Simulation results show the performance of the system over different scenarios.**

I. Introduction

The scope of this investigation deals with the development of communications technologies able to support the increasing data traffic coming from vehicles operating on the airport surface, i.e. mainly aircraft, but also vehicles providing luggage handling, fueling, etc. Currently, for the air traffic data link communications, only the highly congested very high frequency (VHF)-band is used. Moreover, the VHF Digital Link Mode 2 (VDL2) [1] technology, which is currently adopted, cannot satisfy the demand of robustness, security and efficiency required for future aeronautical communications. New bands and new data communication systems have been investigated. For these reasons, new allocations to the aeronautical communications were defined, especially in C band (between 5.091 GHz and 5.150 GHz) for airport surface operations. The standard IEEE 802.16e (WiMAX) [2] [3] has been chosen by the European Organization for the Safety of Air Navigation (EUROCONTROL) and the Federal Aviation Administration (FAA) as the technology for the future Aeronautical Mobile Airport Communications System (AeroMACS). The orthogonal frequency-division multiple-access (OFDMA) mode of the WiMAX standard offers a good resistance against the multi-path effects. Moreover, it includes a large variety of profiles for physical layer coding and modulation, and hence enables the choice of the one which may be most suitable for the airport environment.

The airport channel is mainly characterized by multi-path and Doppler effects. Generally, in line-of-sight (LOS) conditions the system provides good results for all the airport scenarios [4]; though, in non line-of-sight (NLOS) scenarios improvements to the system performance may be worthwhile.

Diversity techniques represent an appealing solution for improving the performance; though, the aeronautical system doesn't consent to introduce an arbitrarily number of antennas, especially on the aircraft. The adoption of a 1×2 single input multiple output (SIMO) scheme could represent a valid solution for the reverse link (RL) [1] case, but not for the FL one. In the FL case a multiple input single output (MISO) scheme should be a candidate, since it avoids the problem of the installation of a second antenna on the aircraft. The implementation of a MISO scheme requires channel state information at the transmitter site, which requires a return channel. However, the typical system frame size of 5 ms and the coherence time of the channel $T_{cho} \approx 2$ ms make providing the channel information at the transmitter side an hard task. The adoption of a 2×1 Alamouti space-time coding (STC) scheme permits to avoid the previous problems and represents a valid solution for the FL case.

In this paper we analyze the performance of the FL based on the OFDMA mode of the WiMAX standard, focusing on the worst channel conditions. In order to improve the performance of the FL in NLOS conditions, we investigate the use of a 2×1 Alamouti scheme and propose a novel STC implementation which permits to preserve the original frame structure of the WiMAX (WiMAX) standard.

Section II recalls the concept of the STC scheme introduced by Alamouti and summarizes their characteristics in an orthogonal frequency-division multiplexing (OFDM) environment. Section IV provides a description of the system, summarizing the main physical layer characteristics of the OFDMA mode of the WiMAX standard and the parameters used for the simulations. The channel model used for the analysis and the parameters chosen for the parking and apron scenarios are also included. Section V provides simulation results for different scenarios in NLOS conditions, with ideal and realistic channel estimations. Section VI concludes the paper summarizing the main outcomes of this work.

II. Alamouti Space-Time Coding

The Space-Time Coding scheme introduced by Alamouti in [5] represents a brilliant solution for all the systems where it is impossible to increase the number of receiving antennas. Without channel state information (CSI) requirements at the

[1] In the aeronautical context, the RL is usually referred to as the link from the aircraft to the control tower, while the forward link (FL) represents the link from the control tower to the aircraft.

transmitter site, it combines the information to transmit over more antennas providing the same diversity gain offered by a classical maximal-ratio receive combining scheme with equal number of branches. The unique requirement of the system concerns the coherence time of the channel. It is necessary to have a sufficiently slow channel, in order to allow the decoding of the signal transmitted over two (or more) antennas and consecutive time instances. In the case 2×1, the two transmitting antennas at a certain symbol period t_1 transmit two different signals s_1 and s_2, respectively. In the following symbol period t_2 the first antenna transmits s_2^*, while the second one $-s_1^*$, as indicated in Fig. 1.

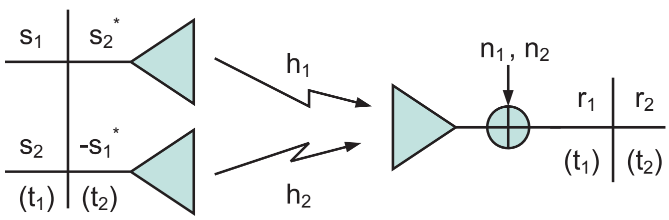

Fig. 1. Scheme of the generic Alamouti's space-time coding scheme.

At the receiver the received signals r_1 and r_2

$$\begin{aligned} r_1 &= s_1 \cdot h_1 + s_2 \cdot h_2 + n_1 \\ r_2 &= s_2^* \cdot h_1 - s_1^* \cdot h_2 + n_2 \end{aligned} \tag{1}$$

are combined obtaining the starting information

$$\begin{aligned} \widehat{s_1} &= r_1 \cdot h_1^* - r_2^* \cdot h_2 \\ \widehat{s_2} &= r_1 \cdot h_2^* + r_2^* \cdot h_1 \end{aligned} . \tag{2}$$

A. Space-Time Coding and OFDM

An OFDM system offers different possibilities for the implementation of the Alamouti scheme. The scheme may be applied to the frequency or time domain; moreover, beside the previously described scheme, it is possible to implement space-frequency coding (SFC), which constitutes the frequency variant of STC. In this case the signals are combined in frequency direction, therefore the requirement on the channel is no longer on the coherence time but on the frequency selectivity. SFC permits to easily counteract the problem of the channel estimation, which constitutes a key issue for STC applied to OFDM systems. This is due to the fact that a combination of two different signals arrives at the receiver. A channel estimation based on the pilot tones of the standard (single antenna case) frame is then unfeasible since the pilot tones would interfere each other.

In order to apply a 2×1 diversity scheme to the WiMAX FL, the standard proposes an implementation of STC based on the modification of the FL frame trough the construction of new clusters [2]. As represented in Fig. 2, the modified clusters have double size with respect to the normal ones (see Section IV and Figure 5) and pilot sub-carriers in different positions. The new structure permits the STC application to consecutive OFDM symbols. Moreover, in order to solve the problem of the channel estimation the pilot symbols are shared between the two antennas, blanking the pilot tones of one antenna in correspondence of the pilot tones assigned to the other antenna.

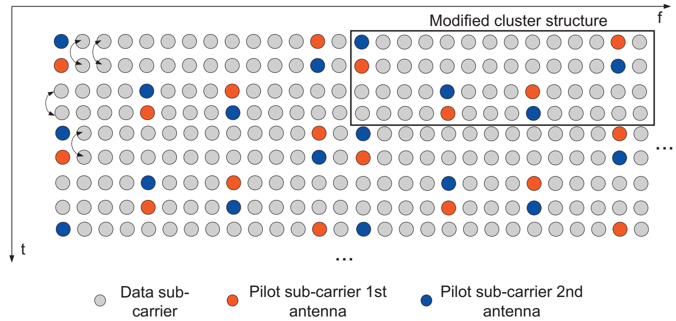

Fig. 2. Generic WiMAX frame structure with space-time coding. The cluster structure is modified with respect to the single antenna case in order to apply STC to consecutive OFDM symbols.

III. Space-Time Coding Implementation

In this work we propose a different STC implementation which doesn't require the modification of the original structure of the frame and therefore also the changing of the channel estimation algorithms. In order to obtain an estimation of both channels, we assume that the channels change only slowly in time and are nearly constant over 4 OFDM symbols. This assumption is indeed realistic, considering that for the aeronautical channel the coherence time is generally in the order of 2 ms [6], while in the AeroMACS case the OFDM symbol duration is around 115.2 μs. Furthermore, we virtually divide the frame in subsets of 4 adjacent OFDM symbols and allocate all the pilot tones of the first two adjacent symbols to the first antenna, while the remaining ones on the other symbols to the second antenna, as showed in Fig. 3.

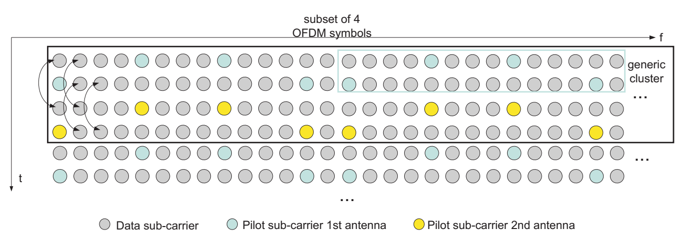

Fig. 3. Generic frame scheme with the proposed pilot tones allocation.

Wherever the pilots of an OFDM symbol are sent through antenna 1, the corresponding sub-carriers in the OFDM symbol sent through the antenna 2 are blanked (see Fig. 4). This assures, that in the received signal the pilot tones can be used to estimate either the channel coefficients from antenna 1 or from antenna 2.

We apply space time coding in the frequency domain between sub-carriers with same frequency position but different OFDM symbols according to the description provided in Fig. 4 and Fig. 3. The generic transmitting symbol $x_{i,j}$ is combined with $x_{i+2,j}$, where i and j respectively represent the time and frequency indexes. Indicating $s_1 = x_{i,j}$ and $s_2 = x_{i+2,j}$, and the corresponding channels with $h_1 = h_1(i,j) \approx h_1(i+2,j)$ and $h_2 = h_2(i,j) \approx h_2(i+2,j)$, we can rewrite (1) and (2) as follow:

$$\begin{aligned} r_1 = r_{i,j} &= x_{i,j} \cdot h_1 + x_{i+2,j} \cdot h_2 + n_1 \\ r_2 = r_{i+2,j} &= x^*_{i+2,j} \cdot h_1 - x^*_{i,j} \cdot h_2 + n_2 \end{aligned} \tag{3}$$

$$\begin{aligned} \widehat{x_{i,j}} &= r_{i,j} \cdot h_1^* - r^*_{i+2,j} \cdot h_2 \\ \widehat{x_{i+2,j}} &= r_{i,j} \cdot h_2^* + r^*_{i+2,j} \cdot h_1 \end{aligned} \tag{4}$$

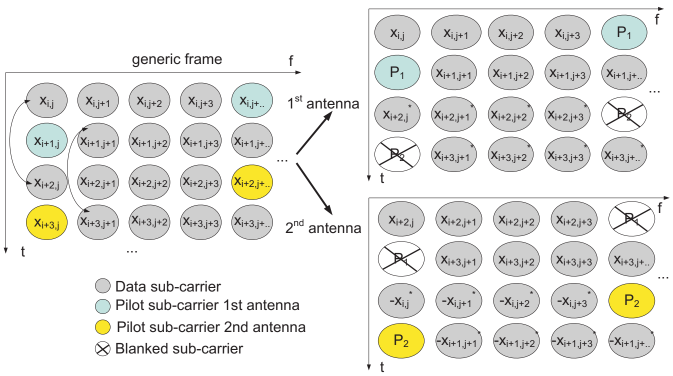

Fig. 4. Scheme of the proposed space time coding implementation. The two frames to be transmitted on the two antennas are generated from the generic frame.

IV. System Description

We analyze a system based on the OFDMA mode of the IEEE 802.16e (WiMAX) standard [3] and in particular the down link (DL) case. The waveform of the system consists of a different numbers of sub-carriers equal to 128, 512, 1024 or 2048. Only the sub-carriers in the center of the bandwidth are effectively used for data transmission and pilot symbols (except the DC sub-carrier, which is nulled). The used sub-carriers may be distributed in the frame according to the partially use of sub-carriers (PUSC) mode. In this case the frame is organized in clusters, as represented in Fig. 5. Two lateral frequency bands are left unused. The cyclic prefix (CP) values may be set within $1/4$, $1/8$, $1/16$ or $1/32$ of the symbol duration.

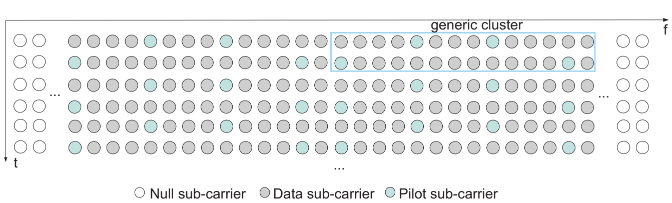

Fig. 5. Scheme of the FL-PUSC frame based on the cluster concept.

The basic coding scheme for this mode includes the convolutional codes (CC) and the Turbo codes with different coding rates. Optional codes are the convolutional turbo code (CTC) and (LDPC). The modulation set for the sub-carriers includes quadrature phase shift keying (QPSK), quadrature amplitude modulation (QAM) with 16 constellation points (16-QAM) and optionally 64-QAM.

A. System parameters

The parameters chosen for the simulations consist of a bandwidth of 5 MHz with subcarrier spacing of roughly 10 kHz, a basic coding scheme with a rate $1/2$ convolutional code and a QPSK subcarrier modulation. Given this sub-carrier spacing and the Doppler spread/shift values provided in Table II, the inter-carrier interference shall provide a negligible impact on the performance. The cyclic prefix has been set $1/8$ of the symbol length, therefore the total OFDM symbol time T_{OFDM} is approximatively 115.2 μs. Frames of 24 OFDM symbols have been considered, with 17 sub-channels allocated to one user. Prior to the modulation, the bits at the output of the convolutional encoder are interleaved over the entire frame.

We considered ideal channel estimation (ID) and two types of linear interpolation based on the pilot tones and tailored for the WiMAX cluster structure. The easiest algorithm performs interpolation in the frequency domain within a single cluster, using only the frequency direction (LIN-freq.). Also the other algorithm operates in the frequency domain but considers both the time and frequency dimensions over the whole frame (LIN-time/freq.). In this second case a first time direction interpolation is used to perform a second more accurate frequency interpolation. Table I provides the system parameters used in the simulations.

TABLE I
Simulation system parameters.

System parameters	**FL - OFDMA**
Bandwidth	5 MHz
FFT size	512
Null guard sub-carriers	91
CP	$1/8 \cdot T_S = 12.8\mu$s
Frame size	24 OFDM symbols
Symbol time T_S	102.4 μs
$T_{\text{OFDM}} = T_S +$ CP	115.2 μs
T_{frame}	2.75 ms
Sub-carrier spacing Δ_f	$\simeq 10$ kHz
Coding, rate	Convolutional, $1/2$
Decoding	Soft Viterbi
Modulation	QPSK
Channel Estimation	ID, LIN-freq., LIN-time/freq.

B. Channel model

For our investigation we used the stochastic airport channel model presented in [4]. It is based on the wide sense stationary uncorrelated scattering (WSSUS) model [7], adapted to the peculiarities of the airport environment as multi-path and Doppler effect. Generally, the airports are characterized by different areas referred to as apron, taxi, parking and runway. These areas correspond to different aircraft conditions and present different propagation conditions. The taxi and runway scenarios represent two movement phases and are characterized by LOS conditions. The parking and apron scenarios correspond to areas close to the buildings and are characterized by no or limited mobility. The presence of the buildings makes the control tower in NLOS and stresses the performance of the system. We considered only the parking and the apron scenarios, which with respect to the others present NLOS conditions. We assumed Rice factor (K) values equal to 0 and -10 dB for the parking case, which is characterized by NLOS conditions for most of the time; while for the apron case we assumed a representative worst case with K = 0 dB. Table II provides the main channel parameters corresponding to the different scenarios used for the simulations.

TABLE II
CHANNEL PARAMETERS OF THE DIFFERENT SCENARIOS.

	APRON	**PARKING**
K [dB]	0	$-10, 0$
Delay spread σ_τ [μs]	0.65	1.25
Doppler spread $\sigma_{D\,min}, \sigma_{D\,max}$ [Hz]	$20, 50$	$10, 40$
Doppler shift $f_{D\,max}$ [Hz]	140	50
Number of taps	9	12

V. RESULTS

In the following we present the simulation results, evaluating the performance of the FL of the OFDMA system with respect to its version with the above-described STC implementation. The results are obtained using the channel described in Subsection IV-B and are presented separately for each scenario. All the performances are shown in terms of bit error rate (BER) versus E_b/N_0. The first figures (Fig. 6 and Fig. 7) represent the results obtained for the parking scenario. This scenario is characterized by a rich multi-path with a large delay spread, while the low mobility results in small Doppler spreads/shifts.

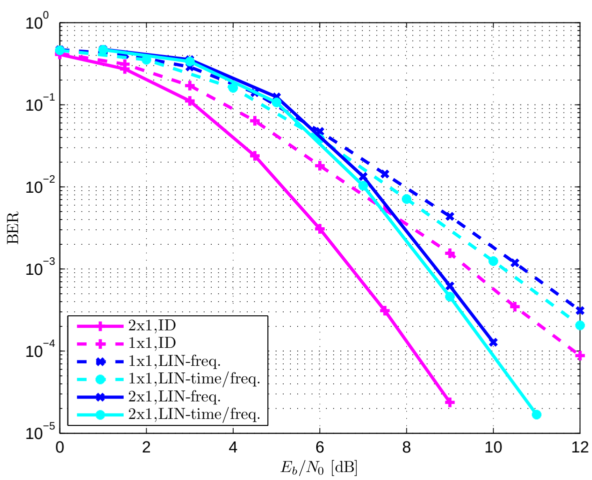

Fig. 6. Parking scenario performance obtained with The FL of a normal OFDMA WiMAX system (no diversity) and the proposed 2×1 STC version of the system. K = 0 dB, evaluation of different channel interpolations w.r.t. ideal channel estimation.

Figure 6 provides the results obtained with Rice factor equal to 0 dB and different channel estimations. The results obtained with linear pilot interpolation are compared with the ones obtained with ideal channel estimation. The presence of the second antenna increases the performance doubling the slope of the curves; though, the real channel estimation case with diversity looses almost 2 dB with respect to the corresponding ideal case. In Figure 7 the performance obtained with K = -10 dB and linear interpolations is shown. Also in this case the introduction of a second transmitting antenna improves the performance doubling the slope of the curves.

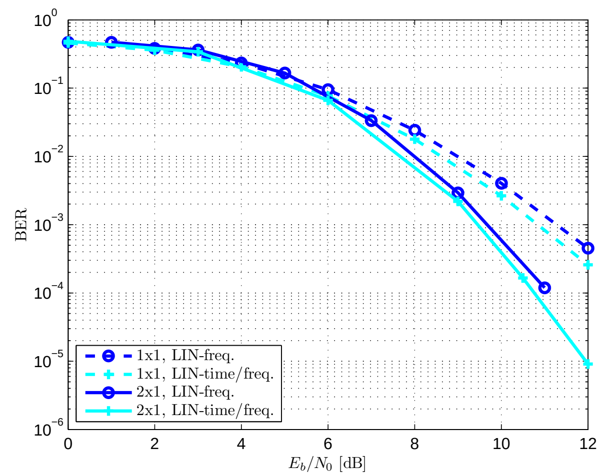

Fig. 7. Parking scenario performance obtained with the 1×1 system and the 2×1 STC system. K = -10 dB and linear interpolation in time and frequency direction.

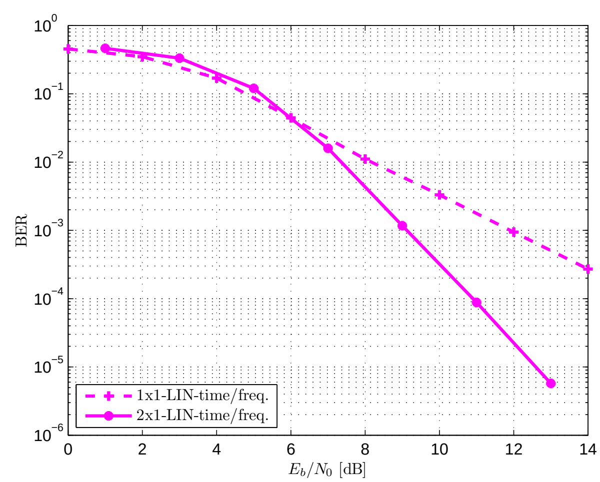

Fig. 8. Apron scenario performance obtained using the system 1×1 without diversity and the system with the proposed 2×1 STC implementation. K = 0 dB and linear interpolation in time and frequency direction.

Figure 8 provides the results obtained for apron scenario. This case is characterized by a delay spread $\sigma_\tau = 0.65$ μs and small values of Doppler spread and shift ($\sigma_D \leq 50$ Hz, $|f_D| < 140$ Hz). We considered only K = 0 dB since with higher Rice factor we would not have improvement by the addition of a transmitting antenna. The results are obtained with linear interpolation in time and frequency directions and show the improvement provided by STC.

VI. Conclusion

In this paper we focused on the future communication system for the airport surface operation based on the WiMAX standard and we evaluated a method for improving its performance in the most critical conditions. Hence, we presented an analysis of the application of the Alamouti scheme to the FL based on the OFDMA mode of the IEEE 802.16e standard. We introduced a novel implementation of 2×1 STC which preserves the basic structure of the system and minimizes the modifications required to the system. We evaluated the proposed implementation over a realistic airport channel with different scenarios. The results, obtained for non line of sight conditions cases, show the improvement introduced by the STC.

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