Transmit Diversity in the Downlink for the TETRA-TEDS System

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Abstract—In the paper a proposal for the improvement of performance for the TETRA Enhanced Data System (TEDS) employing transmit diversity based on two antennas in the downlink is described. The key idea of the considerations relies on using the space-frequency coding algorithm. The proposal described required some relatively simple changes to the existing TEDS’s Single Input Single Output (SISO) interface but the original number of payload and signaling symbols in the normal downlink burst is preserved. The simulation results obtained indicate a significant improvement in performance. The Eb/No parameter could be reduced from 5 to 8 dB with respect to Frame Error Rate (FER), compared to the single antenna transmission for the same FER = 10⁻³.

Keywords—multiple input multiple output (MIMO), TETRA Enhanced Data System.

1. Introduction

For more than two decades worldwide huge development in mobile digital communication systems with continually improving performance can be observed, increasing throughput and an enlarging pool of services available for users. One of the known techniques employed in this progress is Transmit Diversity [4] – Multiple Input Multiple Output (MIMO) due to its ability to form different routes for the transmission of signals over the radio fading channel. Furthermore, such a MISO technique is simple and does not require significant changes in the radio interface.

The TETRA Enhanced Data System (TEDS) [1]–[3] with its radio interface based on filtered multitone modulation (FMT) [4] is suitable for the implementation of MIMO. However, due to the relatively small dimensions of a mobile terminal, the simple version of MIMO – called Multiple Input Single Output (MISO) – is reasonable for TEDS with two transmit antennas at the base station and a single receive antenna at the mobile terminal.

2. Implementation of MISO in the TEDS Radio Interface

In the following, the implementation of MISO based on the Alamouti algorithm [5], [6], for the TEDS radio interface, is described. With FMT modulation the baseband time-continuous signal in TEDS is given by [1], [2]:

\[ s(t) = \sum_{n=0}^{N-1} \sum_{k=0}^{K-1} a_n^{(k)} g(t-nT) e^{j2\pi nkT} e^{j\alpha t}, \]

(1)

where \( n \) is the generic symbol within the burst, \( k \) is the index of the subcarrier, and \( K \) and \( N \) are the number of subcarriers and the transmitted (multicarrier) symbols, respectively.

Moreover, the impulse response of the square-root raised cosine filter has roll-off \( \alpha = 0.2 \), the signaling interval is \( T = 1/2400 \) s and the subcarrier spacing is \( \Delta f = \zeta/T = 2700 \) Hz. Thus, \( \zeta = \Delta f \cdot T = 1.125 \) is the measure of interference between neighboring subcarriers. This means that the frequency occupancy of each subcarrier is \( (1+\alpha)/T = 2880 \) s. As is known, the TEDS interface can be used for channels having the bandwidths: 25 kHz, 50 kHz, 100 kHz and 150 kHz. In order to explain the Double Input Single Output (DISO) for the downlink in the TEDS interface, the structure of Normal Downlink Burst (NDB), for each of the channels should be considered. As an example, in the following the NDB with \( K = 16 \) subcarriers (50 kHz channel) is described (see Fig. 1a). The burst contains the payload symbols (D marks), the header symbols (H marks), the pilot symbols (P marks) and the synchronization symbols (S marks).

To allow for the reception of signals transmitted by two antennas it is necessary to adequately locate the payload, pilot and synchronization symbols in the two symbol streams. Now, the pilot symbols should enable the receiver to carry out the estimation of channel characteristics for each of the symbol streams, and the synchronization symbols should provide efficient receiver synchronization. Of course, the number of payload and signaling symbols in the DISO and SISO schemes must remain identical.

Thus, it is not an easy task to comply with these requirements. A proposal for NDB burst adapted for DISO in the downlink is shown in Fig. 1b [7]. The pilot and synchronization symbols transmitted by the first and second antenna are marked by R and L, respectively. In the original Alamouti algorithm two symbols representing a pair are transmitted in two consecutive symbol times. Since the symbol time is small compared to the coherence time of the channel, the authors assume that, in practice, the channel characteristics are almost the same for both symbols.

Of course, in the multicarrier system the channel characteristic is a function of time and frequency [8]. However, if the channel characteristic is quasi-stationary in the small time interval (for two symbols), it is also quasi-stationary in the small frequency spacing concerning two neighboring subcarriers. As a result, a pair of symbols in the Alamouti algorithm may be represented either in frequency or time domain. The Alamouti algorithm in the proposal consid-
ered has been adapted to the format of the transmitted signal in such a way that the time-dependent variable in the original algorithm has been replaced with frequency-dependent variable. In this way a space-frequency coding has been achieved and the dependence on the speed of changes in channel characteristics has been minimized. Figure 2 shows the fragment of the burst in which the data symbols \( a_n^{(k)} \) presented in Eq. (1) are assigned to the suitable antennas and subcarriers [7].

As can be seen in Fig. 2, it is possible to separate \( \left( a_n^{(k)}, a_{n+1}^{(k+1)} \right), \left( a_{n+2}^{(k+2)}, a_{n+3}^{(k+3)} \right) \) etc., which appear in both channels on the subcarriers having the same index. Furthermore, the symbols in each pair are assigned to neighboring subcarriers. Since the frequency spacing between the neighboring subcarriers is small, one can assume that each channel associated with a given antenna produces almost the same effect on both symbols of a pair.

The received pair of symbols can be written as the sum of transmitted symbols multiplied by the corresponding channel associated with a given antenna produces almost the same effect on both symbols of a pair.

![Fig. 2. Assignment of successive data symbols (indicated by the subscripts) in the burst to the subcarriers (indicated by the superscripts) and antennas, where symbol \( * \) is the complex conjugate of the argument.](image)

![Fig. 1. Burst structures in the downlink for: (a) SISO and (b) DISO.](image)
To improve the reception performance, the number of these events is reduced by the adequate distribution of payload, pilot and synchronization symbols within the burst.

The reception rule is based on Maximum-Ratio-Combining (MRC) \[5\], \[6\]:

\[
\begin{align*}
\hat{r}_n(k) &= \left( H_L^{(k,k+1)} \right)^* r_n(k) + H_R^{(k,k+1)} r_{n+1}(k+1), \\
\hat{r}_n(k+1) &= \left( H_R^{(k,k+1)} \right)^* r_{n+1}(k) - H_L^{(k,k+1)} r_n(k+1).
\end{align*}
\]

In the Eqs. given by (3), a soft value for each received bit $b_r$ of each symbol is calculated provided that a given bit $b$ was transmitted. To obtain the likelihood of this bit such symbol $d_i^{(m)=x}$, $x \in \{0,1\}$, must be found in the constellation of symbols for QAM modulation which takes on the value $x$ in the $m$-th position of a group of bits representing that symbol and minimizes the function

\[
- \log(p(b_r \mid b^{(m)} = x)) \approx \min_{i} \left( \frac{\hat{r}_n(k)}{r_n(k)} - \left( |\hat{H}_R^{(k,k+1)}|^2 + |\hat{H}_L^{(k,k+1)}|^2 \right) d_i^{(m)=x} \right)^2.
\]

This approach is employed for each bit of each symbol in the received sequence of symbols.

3. Simulator for the Transmit Diversity of the TEDS Interface and Simulation Results

To investigate the performance of the above described transmit diversity method in the downlink the simulator shown in Fig. 3 has been developed [7]. The FMT modulator and demodulator used in the investigations are based on the overlap-add algorithm [9]. The rate 1/3 turbo encoder is formed by two recursive systematic convolutional encoders with 8 states each, separated by an interleaver [10]. The code rates 1/2 or 2/3 can be obtained by adequately puncturing the turbo code sequence. In the iterative turbo decoder the Max-Log-Map algorithm [6], [11] was used and the number of iterations is 10.

The selected results of simulations are shown in Figs. 4–7. They represent the relationships between FER and Eb/No for the system identified by: 16 subcarriers (50 kHz bandwidth), 1/2 code rate, 4QAM modulation on each subcarrier, the downlink transmission on 400 MHz in the typical urban (TU) and hilly terrain (HT) propagation profiles [3] and terminal speed of 50 km/h and 200 km/h, respectively.

The curves in the figures denoted by $TD$ represent the results obtained when transmit diversity is employed, and the curves with that denotation missing correspond to the SISO operation. It can be seen from the figures that
the proposed method provides a significant advantage. The \( \text{Eb/No} \) for the DISO configuration is reduced by 5–8 dB for \( \text{FER} = 10^{-3} \) as compared to the SISO. This transmit diversity gain is achieved irrespective of the propagation profile (TU or HT). Moreover, in both cases (with and without TD) one can notice that performance improves when terminal speed increases. This effect is obtained due to the decreased correlation time of fading, particularly as packet interleaving is not used. The results of the investigations also show that halving the number of symbols used for estimation of each channel characteristic with TD, provides sufficiently accurate channel characteristics. However, the transmit diversity gain was reduced to 5 dB for high terminal speed where the fluctuations in channel characteristics are greater. One of the reasons for this reduced gain is the reduced number of symbols used for the estimation of channel characteristics. Nevertheless, the proposed transmit diversity provides a significant improvement in system performance at the cost of an acceptable increase in complexity.
The approach presented in this paper can easily be employed for channels with other bandwidths of the TEDS radio interface.

References


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