Compatible Improvement of the GSM/EDGE System by Means of Space-Time Coding Techniques

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EXTENDED ABSTRACT

Space-time codes (STC) are wireless transmission techniques utilizing multiple transmit antennas (and optionally multiple receive antennas) and have recently gained much interest. The efficiency of STC in fading environments is based on a diversity gain: Given sufficient antenna spacing, the $n_T n_R$ transmission paths from the n_T transmit (Tx) antennas to the n_R receive (Rx) antennas can be regarded as statistically independent. Thus, the probability that each path is degraded at the same time is significantly smaller than the probability that a single path is in a deep fade. The diversity gain obtained by means of STC enables a better bit error performance and therefore – in systems employing adaptive channel coding – higher data rates. The popularity of STC is especially due to the fact that wireless services are often *asymmetric*, where the downlink direction (from the base station (BS) to the mobile station (MS)) carries the predominant part of the overall data traffic. Since multiple Rx antennas are optional with STC, only the BS needs to be equipped with additional antennas instead of upgrading all MS.

The delay diversity scheme [1] and the Alamouti scheme [2] are two particularly simple, but nonetheless efficient STC techniques. In the delay diversity scheme, the same signal is transmitted over each antenna, where at Tx antenna i, $1 \leq i \leq n_T$, a delay $(i-1)T$ is applied (T denotes the symbol interval). The Alamouti scheme employs just $n_T = 2$ Tx antennas. The data symbols are processed as pairs $(x(k), x(k+1))$ and are transmitted using two consecutive time instants. In this context, a mapping of $x(k)$ and $x(k+1)$ onto the two antennas is performed in such a way that at time index k, Tx antenna 1 transmits $x(k)$ and Tx antenna 2 transmits $x(k+1)$, whereas at time index $k+1$ Tx antenna 1 transmits $-x^*(k+1)$ (* denotes complex conjugation) and Tx antenna 2 transmits $x^*(k)$ (*spatial* redundancy). Note that there is no rate loss w.r.t. the conventional single Tx antenna system ((1x1)-system).

In [3] the application of the delay diversity scheme and the Alamouti scheme in a GSM/EDGE system is investigated, especially with regard to compatibility with current specifications. EDGE ('Enhanced Data Rates for GSM Evolution') is an evolution of GSM for the purpose of data rate enhancement. In EDGE most elements of the GSM physical layer are reused (e.g., carrier frequencies, burst structure, training sequences, etc.), so as to enable a smooth transition. The 2-ary GMSK modulation scheme of GSM is as well retained. Additionally, EDGE offers an 8-ary modulation scheme using 8-PSK mapping in conjunction with the same Gaussian pulse shape as used in GMSK, i.e., the raw data rate is triplicated.

The following topics are, among others, addressed in [3]: A compatible transmitter structure is presented for both STC schemes and the performance improvements obtainable on a typical urban (TU) channel are demonstrated on basis of simulation results. The influence of fast fading as well as of non-perfect knowledge of the channel coefficients in the receiver is also investigated. For the Alamouti scheme, novel partner sequences w.r.t. the 8 GSM training sequences are presented. They yield excellent cross-correlation properties, that are crucial in order to enable accurate channel estimation. Moreover, a new trellis-based equalizer/detector algorithm is derived for the Alamouti scheme, which is characterized by the same complexity as in case of the (1x1)-system. For the delay diversity scheme, employing n_T=2 Tx antennas and an arbitrary delay δ at the second antenna, a lower bound on the bit error probability is derived, which is then utilized in order to optimize the delay parameter δ.

Here, focus shall be on the latter topic. The so-called RAKE receiver bound (RRB) is a lower bound on the bit error probability of a slowly time-varying intersymbol interference (ISI) channel, where perfect knowledge of the channel coefficients at the receiver is presumed. The channel coefficients are assumed to fade *independently*. In case of maximum likelihood (ML) detection, the RRB is given by

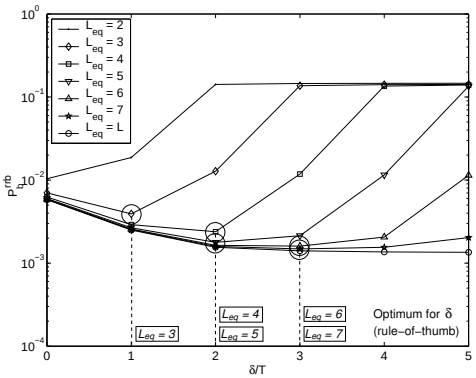

Fig. 1. RRB as a function of δ for different equalizer lengths L_{eq}, TU-profile, $E_s/N_0 = 10$ dB (analytical results, ZF equalization applied).

$$P_b^{\mathrm{rrb}} = \frac{1}{2}\sum_{\lambda=0}^{L}\left(\prod_{\substack{\nu=0\\ \rho_\nu \neq \rho_\lambda}}^{L}\frac{\rho_\lambda}{\rho_\lambda-\rho_\nu}\right)\cdot\left(1-\frac{1}{\sqrt{1+\frac{N_0}{E_s}\,\frac{1}{\rho_\lambda}}}\right), \quad (1)$$

where L denotes the channel memory length, E_s the mean energy per data symbol, N_0 the single-sided noise power density, and ρ_λ the mean power of the λth channel coefficient, $0 \leq \lambda \leq L$. In case of a truncated trellis-based equalizer/detector, which only takes into account the first $L_{eq}+1$ channel coefficients ($L_{eq} < L$), the sum and the product in (1) are from 0 to L_{eq}. The neglected channel coefficients cause residual ISI, resulting in a transformed signal-to-noise ratio $(E_s/N_0)'$.

Since in the delay diversity scheme the same signals are transmitted over both antennas, it is possible to derive an equivalent single Tx antenna channel model. Specifically, one obtains the following expression for the mean power of the λth coefficient of the equivalent channel model:

$$\rho_\lambda(\delta) = \int_0^{\tau_{max}} p(\tau)\left(|g(\lambda T-\tau)|^2 + |g(\lambda T-\delta-\tau)|^2\right)d\tau\,, \quad (2)$$

where $g(t)$ denotes the overall impulse response of pulse shaping filter and receiver filter. The pdf $p(\tau)$ is proportional to the delay power density profile (e.g., one of the GSM 05.05 propagation profiles).

Due to the fact that the channel coefficients are assumed to fade independently, the RRB tends to be too optimistic since normally the channel coefficients do not only comprise *dynamic* ISI, which is due to the physical channel, but as well *static* ISI, which is due to the filter $g(t)$ and which does not yield any diversity gain at all. In [3], the RRB is therefore tightened by applying a zero-forcing (ZF) equalizer to the channel coefficients so as to eliminate the influence of the static ISI. Fig. 1 shows the RRB as a function of δ given different equalizer/detector lengths L_{eq} (TU-profile, $E_s/N_0 = 10$ dB). Obviously, if $L_{eq} = L$, then the delay δ should be chosen $\delta \geq 3T$. For $L_{eq} < L$ a rule-of-thumb concerning the optimum choice of δ can be derived from Fig. 1, namely $\delta_{opt} \approx \lfloor L_{eq}/2 \rfloor \cdot T$.

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