# Chip interleaved turbo codes for DS-CDMA mobile radio in fading channel

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A new channel interleaving method, called chip interleaving, for direct sequence code division multiple access (DS-CDMA) is proposed. A chip interleaver scrambles the chips and transforms the transmission channel into a highly time-selective or highly memoryless channel. It was found that the turbo decoding performance which degrades in a fading channel is significantly improved with chip interleaving.

*Introduction:* Turbo codes [1] have been found to give performance close to the Shannon capacity in an additive white Gaussian noise channel; however, in a fading environment the performance degrades drastically, even with channel interleaving. This is because the fading channel cannot be memoryless with a conventional channel bit-interleaving. In direct sequence code division multiple access (DS-CDMA) mobile radio, the data sequence to be transmitted is spread over a wideband channel by multiplying each bit by a spreading code. The resulting sequence is said to be composed of chips, to contrast them from the sequence before spreading. The chip sequence is then transmitted over the wireless channel. In this Letter, we propose a new channel interleaving method, called chip interleaving. At the transmitter, a chip interleaver scrambles the chips associated with a data symbol so that the channel gains experienced by neighbouring chips are highly uncorrelated. By doing so, the resultant transmission channel can be transformed into a highly time-selective or highly memoryless channel. At the receiver side, the received chips are first de-interleaved and processed further. Hence, during the despreading operation, the fading effect is significantly reduced, thereby improving the turbo decoding performance.

*Transmission system model with chip interleaving:* Fig. 1 shows the DS-CDMA transmission system model with a chip interleaver/de-interleaver. The spread chip sequence $\{s_i\}$ to be transmitted can be expressed in the equivalent lowpass form as

$$s_i = \sqrt{2S}c_i \tag{1}$$

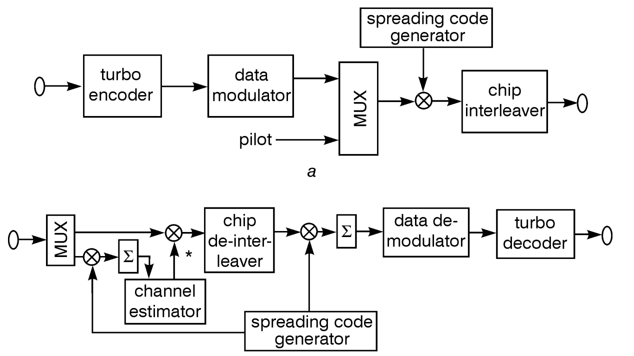


**Fig. 1** *DS-CDMA transmission model*

*a* Transmitter
*b* Receiver

where $S$ is the average signal power, $c_i = d_n \cdot pn_i$, $n = i \bmod SF$, with $SF(= T/T_c)$ representing the spreading factor, $\{d_n\}$ is the binary phase shift keying (BPSK) symbol sequence with the symbol length $T$, and $\{pn_i\}$ is the spreading sequence with chip length $T_c$. The chip interleaver accepts blocks of chips and interleaves them, giving the new spread sequence $\{s_j\}$ which is transmitted over the channel. The idea is to distribute the chips belonging to a bit as far as possible such that the channel gains on these chips are highly uncorrelated. Hence, the size of the chip interleaver is an important design parameter. Pilot symbols are inserted in the data sequence to assist in channel estimation. Fig. 2 shows the chip interleaver assumed here, which is an $SF \times N(1 + N_p/N_d)$-block interleaver, where $N$ is the coded sequence size. The chip interleaver is designed such that $(N_p \times SF)$ pilot chips appear every $(N_d \times SF)$ data chips in the interleaved sequence to assist in channel estimation. The received sequence $\{r_j\}$ may be expressed as

$$r_j = \sqrt{2S}\xi_j c_j = n_j \tag{2}$$

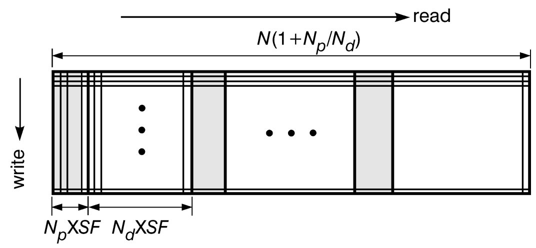


**Fig. 2** *Chip interleaver structure*

where $\xi_j$ is the complex fading channel gain associated with the $j$th chip and $\{n_j\}$ is the Gaussian random process with mean 0 and variance $2N_0/T_c$, where $N_0$ is the single-sided additive white Gaussian noise (AWGN) power spectrum density. Assuming a Rayleigh fading channel, $\{\xi_j\}$ is a complex Gaussian process with mean 0 and variance 1. Pilot chips are extracted, despread and manipulated for channel estimation. Coherent detection of the received spread signal is first performed in a chip-wise manner and then de-interleaved. The chip de-interleaved sequence is represented by

$$\hat{r}_i = \sqrt{2S}\xi_i\hat{\xi}_i^* d_n pn_i + n_i\hat{\xi}_i^* \tag{3}$$

where $\hat{\xi}_i$ is the estimated channel gain associated with the $i$th chip and $(\cdot)^*$ represents the complex conjugate. The chip de-interleaved sequence is despread, i.e. multiplied by the locally generated spreading sequence $\{pn_i\}$ and summed up over one BPSK symbol period $T$. After despreading, data demodulation is performed to obtain the soft values used for turbo decoding:

$$\hat{d}_n = \sqrt{2S}d_n \mathrm{Re}\left(\sum_{i=nSF}^{(n+1)SF-1} \xi_i\hat{\xi}_i^*\right) + \mathrm{Re}\left(\sum_{i=nSF}^{(n+1)SF-1} n_i\hat{\xi}_i^*\right) \tag{4}$$

where Re($z$) is the real part of $z$. It should be noted that the channel gains $\{\xi_i,\ i = nSF \sim (n+1)SF - 1\}$ are collected from widely spread time positions. Hence, the fading nature experienced after despreading tends to disappear as a result of chip interleaving. This is equivalent to space diversity reception with $SF$ antennas but with correlated fading. Thus, the deep fades in the channel have been effectively avoided. The soft values are input to the turbo decoder. Turbo decoding is based on the assumption that the channel is memoryless. Using a chip interleaver/de-interleaver helps to realise this assumption even in a slow fading channel that is not actually memoryless.

*Computer simulation results:* For simulation purposes, we consider a rate 1/2 (punctured from rate 1/3) turbo code made from two (13,15) recursive systematic encoders with an S-random interleaver [2] between them with $S \simeq K^{1/2}$, where $K = 2^{13}$ bits is the information sequence length. Spreading sequence $\{pn_i\}$ is a pseudonoise (PN)-sequence of period 4096 chips. $SF = 32$ is assumed. Pilot symbol based channel estimation is carried out using the weighted multi-slot averaging (WMSA) method [3] with $N_p = 4$ symbols and $N_d = 32$ symbols. The size of the chip interleaver of Fig. 2 is thus 32 × 18432. The channel is assumed to be a frequency non-selective slow Rayleigh fading channel with $f_D T = 0.001$, which corresponds to a maximum Doppler frequency of 128 Hz for an information data rate of 64 k bits/s and a chip rate of 4.096 M chips/s. The turbo decoder is based on the log-MAP algorithm [4]. The simulation results are shown in Fig. 3, which plots the bit error rate (BER) performance against the signal energy per information bit-to-AWGN power spectrum density ratio $E_b/N_0$ with chip interleaving and bit interleaving. For comparison, the BER performance curve assuming perfect bit interleaving is also plotted. Let us first concentrate on the BER curves with bit interleaving (solid curves). It is seen that, compared to perfect bit interleaving, the required $E_b/N_0$ for BER $= 10^{-4}$ degrades by nearly 2.5 dB with the $128 \cdot 128$ bit channel interleaving. WMSA channel estimation further degrades the performance by 1.5 dB. The dashed curves are the BER curves with chip interleaving. The performance is always better than with bit interleaving. Compared to the $128 \cdot 128$ bit interleaving, chip interleaving reduces the required $E_b/N_0$ for $\mathrm{BER} = 10^{-4}$ by nearly 2.6 dB for ideal channel estimation. Similar improvement is seen when WMSA channel estimation is used. It is interesting to note that the BER performance with chip interleaving and WMSA channel estimation is better than that with $128 \cdot 128$ bit interleaving and ideal channel estimation.

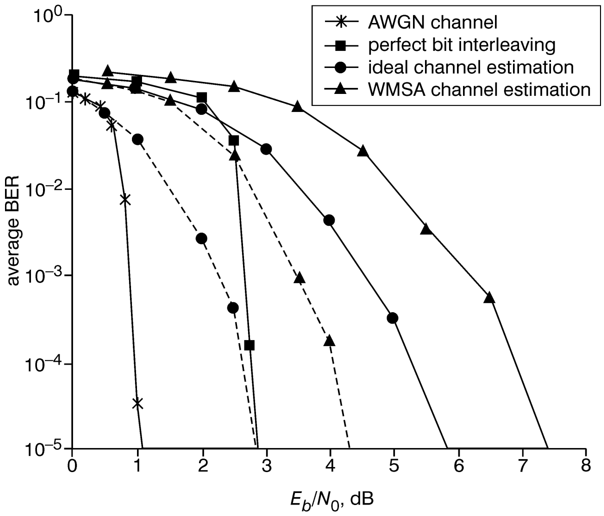


**Fig. 3** *BER performances with and without chip interleaving*

- - - - - with chip interleaving
——— without chip interleaving

*Conclusion:* A new channel interleaving method, called chip interleaving, is proposed for DS-CDMA mobile radio in a multipath fading channel. Chip interleaving scrambles the chips and transforms the transmission channel into a highly time-selective or highly memoryless channel. It was shown by computer simulation that the turbo decoding performance which degrades in a fading channel is significantly improved when chip interleaving is used instead of conventional bit interleaving. A fairly large-sized chip interleaver is necessary. How the chip interleaver size impacts the achievable BER performance is left for a future study.

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