TTCM Assisted Genetic-Algorithm Aided Reduced-complexity Multiuser Detection

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Abstract

Turbo Trellis Coded Modulation assisted Genetic-Algorithm aided reduced-complexity Multiuser Detection (TTCM-GA-MUD) is capable of providing a considerable coding gain of 2.9 dB without any bandwidth expansion at a BER of 10^{-4} , while maintaining a complexity reduction factor 8.59×10^6 compared to the optimum multiuser detector in the context of 16QAM transmissions, while supporting $K = 10$ users.

Introduction: The optimal Code Division Multiple Access (CDMA) Multiuser Detector (MUD)[1] based on the Maximum-Likelihood (ML) detection rule performs an exhaustive search of all the possible combinations of the K number of users' M-ary symbol sequences and then selects the most likely combination from the set of M^K legitimate combinations as the K-component M-ary detected symbol sequence. Since an exhaustive search is conducted, the computational complexity of the detector increases exponentially with the number of users K as well as with the number of phasors in the modulation constellation employed. Genetic Algorithms (GAs) have been used for efficiently solving combinatorial optimisation problems in numerous applications [2]. Recently, GA assisted MUD (GA-MUD) has been studied using Binary-Phase-Shift-Keying (BPSK) modulation in the context of a CDMA system [3, 4], which exhibits a substantially reduced complexity compared to the optimum MUD, while maintaining a similar performance. Turbo Trellis Coded Modulation (TTCM) [5] is a channel coding scheme, which has a structure similar to that of the family of power efficient binary turbo codes, but avoids extending the the required bandwidth by absorbing the parity bits upon extending the phasor constellation.

TTCM-GA-MUD: We consider a synchronous CDMA uplink system as illustrated in Figure 1, where K users simultaneously transmit data packets of 1000 TTCM encoded symbols using M-ary modulation to a MUD over AWGN channels. The TTCM scheme employed a code memory of three and four turbo decoding iterations. The received signal can be written as : $r(t) = s(t)+n(t)$, where $s(t)$ is the sum of the transmitted signals of all users and $n(t)$ is the zero-mean complex AWGN with independent real and imaginary components, each having a double-sided power spectral density of $\sigma^2 = \frac{N_0}{2}$. It can be shown that the Log-Likelihood Function (LLF) for a vector $\boldsymbol{b}$ is given by [1]: $LLF(\boldsymbol{b}) = -\frac{1}{2\sigma^2}\int_0^{T_b}|r(t)-s(t)|^2\,dt = -\frac{1}{2\sigma^2}\left\{\int_0^{T_b}|r(t)|^2\,dt - \Omega(\boldsymbol{b})\right\}$. where $\Omega(\boldsymbol{b}) = 2\Re\left[\boldsymbol{b}^H\boldsymbol{C}^*\boldsymbol{Z}\right] - \boldsymbol{b}^H\boldsymbol{C}^*\boldsymbol{RCb}$, $\boldsymbol{R}$ is the $(K\times K)$-dimensional user signature sequence cross-correlation matrix of the K different signature sequences $a_k(t)$, $k \in \{1,\ldots,K\}$, $\boldsymbol{Z}$ is the output vector of the matched filters, $\boldsymbol{b} = [b_1,\ldots,b_K]^T$ is the complex K-component M-ary symbol vector of the K users, and $\boldsymbol{C}$ is the complex channel impulse response vector of the links between the transmitters and receiver. More specifically, for transmission over a non-dispersive AWGN channel, $\boldsymbol{C}$ is a diagonal unity matrix. The notations $(.)^H$ and $(.)^*$ represent the complex conjugate transpose and complex conjugate of the matrix (.), respectively.

The decision rule for the optimum-MUD scheme based on the ML criterion is to choose the specific M-ary symbol combination $\boldsymbol{b}$ from the set of M^K possible combinations of the K number of M-ary users, which maximises the correlation metric $\Omega(\boldsymbol{b})$, yielding $\hat{\boldsymbol{b}} = \arg\left\{\max_{\boldsymbol{b}}\left[\Omega(\boldsymbol{b})\right]\right\}$. Here, the optimum decision vector $\hat{\boldsymbol{b}}$ represents the *hard decision* values for a specific K-symbol combination of the K users during an M-ary symbol period. Based on the *hard decision* vector component $\hat{b_k}$ of vector $\hat{\boldsymbol{b}}$, we derived the log-likelihood channel metrics for the k^{th} user's TTCM decoder for all the M possible M-ary modulated symbols as: $P_{k,m}(\hat{b_k}|b_{k,m}) = -\frac{|\hat{b_k}-b_{k,m}|^2}{2\sigma^2}$, where $b_{k,m}$ is the m^{th} phasor in the constellation space and $m \in \{0,\ldots,M-1\}$. Note that it is possible to obtain the *soft decision* metrics for the optimum-MUD, although its employment imposes a higher complexity. Specifically, given $r(t)$ and all possible $LLF(\boldsymbol{b})$ values, we derived the *soft decision* metrics as: $P_{k,m}(r(t)|b_{k,m}) = ln\left\{\sum_{(if\ b_{k,m}=b_k)}^{(all\ possible\ \boldsymbol{b})} exp(LLF(\boldsymbol{b}))\right\}$.

Our proposed reduced-complexity TTCM-GA-MUD scheme employed the *hard decision* metric and performed only a partial search, rather than full search, using the objective function of $exp(\Omega(\boldsymbol{b}))$. The configuration of the GA employed in our system is shown in Table 1. For a detailed description of the GA-MUD, the readers are referred to [3]. In general, the detection complexity of the GA-MUD is governed by the required number of GA generations Y and populations P, which ensure a reliable decision. The computational complexity of the GA, quantified in the context of the total number of objective function evaluations is related to $P \times Y$.

Simulation results: We found -although not explicitly shown here due to lack of space- that for detecting K users each employing M-ary modulation, the rule of thumb quantifying the required complexity of the TTCM-GA-MUD scheme is given by $P \times Y \approx \frac{1}{2}K^2M^2$, where $P \approx KM$ and

$Y \approx \frac{1}{2}KM$, which attains a performance similar to that of the optimum MUD. **Hence, the computational complexity reductions obtained by the TTCM-GA-MUD compared to that of the optimum MUD can be construed to be about $F = \frac{M^K}{\frac{1}{2}K^2M^2} = 2M^{K-2}K^{-2}$.** For the specific example of $K = 10$ and $M = 16$, the complexity reduction factor F was 8.59×10^6.

In Figure 2, we show the Bit Error Ratio (BER) versus signal to noise ratio per bit, namely E_b/N_0, performance of the TTCM-GA-MUD and that of the TTCM-optimum-MUD schemes, when communicating over AWGN channels using both Quadrature-PSK (QPSK) and 16-level Quadrature Amplitude Modulation (16QAM) TTCM. It is shown in Figure 2 that the optimum-MUD exhibits an approximately 0.3 dB performance loss both in conjunction with *hard-* and *soft decisions*, when K increased from one to four. At $K = 10$, the performance loss of TTCM-GA-MUD is about 1 and 3 dB, as shown in Figure 2 compared to the TTCM-assisted single user schemes employing *hard-* and *soft decisions*, respectively, regardless whether QPSK or 16QAM modulation schemes were used.

Conclusions: In this contribution, we proposed a reduced-complexity TTCM-GA-MUD scheme, which is capable of maintaining a performance similar to that of the optimum-MUD. For $K = 10$ users and a BER of 10^{-4}, the TTCM-GA-MUD aided QPSK and 16QAM systems achieved an SNR-reduction of 3.8 and 2.9 dBs at the effective throughputs of 1 and 3 bit/symbol in comparison to the single user bounds of uncoded BPSK and uncoded 8-level PSK (8PSK), respectively, without extending the required bandwidth. The complexity reduction factors of $F = 1.31 \times 10^3$ and $F = 8.59 \times 10^6$ were achieved for $M = 4$ and $M = 16$, respectively, when supporting $K = 10$ users,

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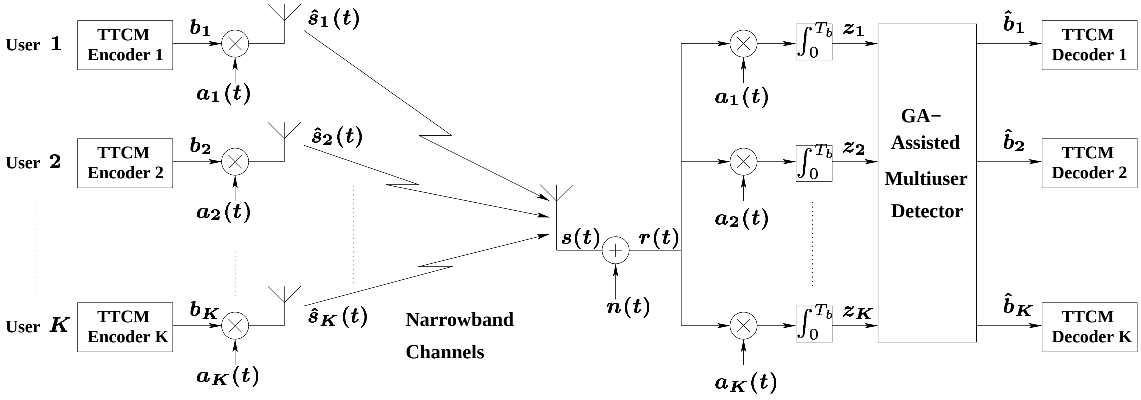

Figure 1: Block diagram of the K-user synchronous CDMA uplink model.

Table 1: The configuration of the TTCM-GA-MUD employed in our system.

Setup/Parameter	**Method/Value**
Selection method	Fitness-proportionate
Crossover operation	Uniform crossover
Mutation operation	Standard binary mutation
Elitism, Incest Prevention	Yes
Population size P	KM
Mating pool size T	$T \leq P$
Probability of mutation p_m	0.1
Termination generation Y	$\frac{1}{2}KM$
M-ary modulation M	4(QPSK), 16(16QAM)
Spreading factor	31 chips
TTCM interleaver length	1000 symbols

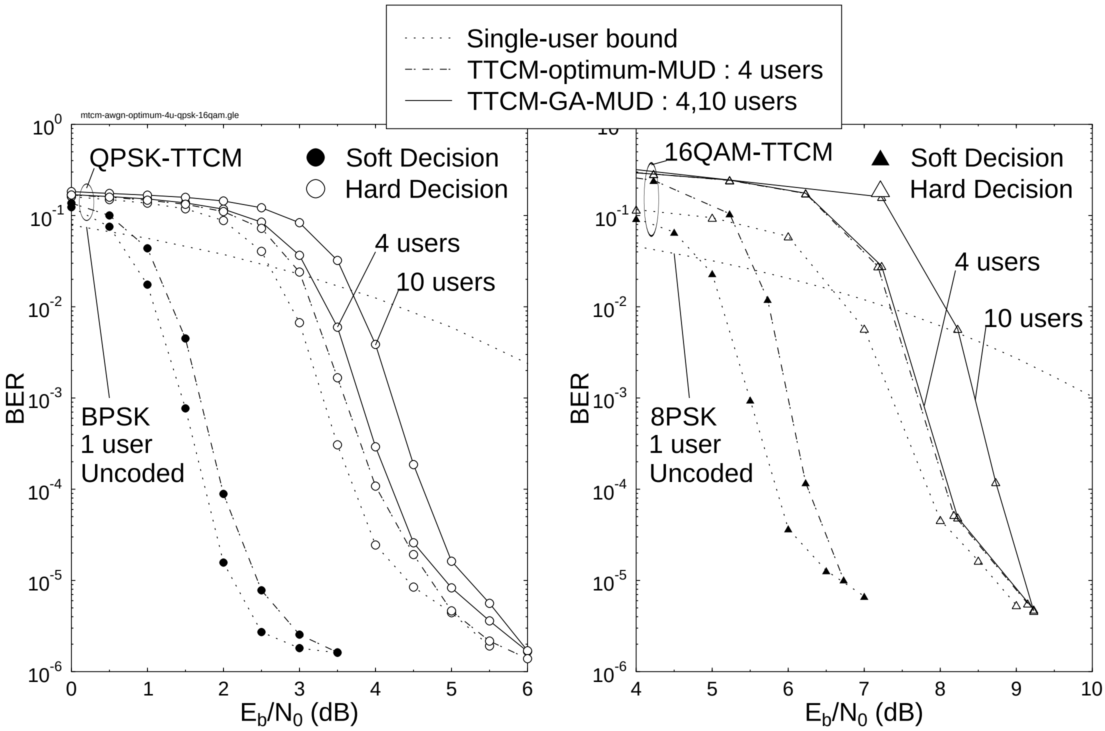

Figure 2: BER versus E_b/N_0 performance of the TTCM-GA-MUD and TTCM-optimum-MUD schemes, when communicating over non-dispersive AWGN channels; left: effective throughput of 1 bit/symbol; right: effective throughput of 3 bit/symbol.

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