The synergy between frequency and phase modulation (FPM) using trellis-coded modulation (TCM) leads to greater gains than can be achieved using conventional TCM/MPSK modulation. An iterative structure is introduced into a TCM/FPM scheme to give a new scheme, the Turbo TCM/FPM scheme. Simulation results show that the new scheme can achieve a significant performance improvement with respect to the Turbo TCM 8PSK and TCM/FPM schemes, respectively, in a DS/SSMA system over a multipath Rician fading channel.

1. INTRODUCTION

The straightforward Turbo Trellis Coded Modulation (TTCM) scheme, proposed by Robertson et al [1], achieves a good error performance on both AWGN channel and fading channel without sacrificing the bandwidth efficiency because it takes the advantage of both iterative concept and spectral saving of TCM scheme. In [1], the coded bits are mapped into two-dimensional signal constellation of M-PSK and M-QAM. Padovani and Wolf [2] proposed several trellis codes for combined frequency/phase modulation (FPM) and achieved higher asymptotic coding gains (ACG) than Ungerboeck’s trellis codes for MPSK. Compared with 8PSK, larger Euclidean distance (ED) at the first step of set partitioning leads to a larger ACG.

In this paper, motivated by the above work, we investigate the performance of Turbo TCM/FPM scheme in a DS/SSMA system over a multipath Rician fading channel. The twisted angle of the two frequency planes according to the different modulation indices in FPM is discussed in detail. Multiple access interference in DS/SSMA system is approximated as a Gaussian distributed random variable during the simulation.

2. SYSTEM MODEL

Figure. 1 shows the block diagram of Turbo TCM/FPM scheme in a DS/SSMA system with L users. In the Turbo TCM/FPM encoder block, a punctured coded bit stream is obtained when the respective information bits pass through ENC1 and ENC2 connected by an interleaver. These coded bits are then allocated to 2FSK/4PSK modulator, signal constellation according to certain rules called ”mapping by set partitioning” is shown in Figure. 2, where φ denotes the twisted angle of two frequency planes. One bit is used to select one of the two frequency planes which are taken to be \((f_c + h/2T)\) and \((f_c - h/2T)\), where \(f_c\) is the center frequency, \(h\) is the modulation index and \(T\) is the signaling interval. The remaining two bits are used to select one of the four phase shifts of the corresponding frequency plane. The resulting signal space is four-dimensional and can be represented by four orthogonal basis functions denoted by \{ \(\psi_1(t)\), \(\psi_2(t)\), \(\psi_3(t)\), \(\psi_4(t)\) \}[2]. Then the transmitted signal \(S_1(t)\) can be written as:

\[
S_1(t) = s_{11}\psi_1(t) + s_{12}\psi_2(t) + s_{13}\psi_3(t) + s_{14}\psi_4(t)
\]

Thus, the minimum squared Euclidean distance between any two signals can be obtained:

\[
\Delta^2_{ij} = (s_{i1} - s_{j1})^2 + (s_{i2} - s_{j2})^2 + (s_{i3} - s_{j3})^2 + (s_{i4} - s_{j4})^2
\]

Obviously, the codes for Turbo TCM/FPM have a different power spectral density than that of the Turbo TCM 8PSK, while they have exactly the same power spectral density as TCM/FPM with the same \(h\) and \(\phi\). According to the 90 and 99 percent bandwidths which are defined in [2], we note that Turbo TCM/FPM scheme requires slightly less bandwidth than Turbo TCM 8PSK scheme when we use 99 percent bandwidth. In this case, there is no sacrificing of bandwidth for Turbo TCM/FPM scheme. The Turbo TCM/FPM decoder is
implemented using symbol-by-symbol Log-MAP algorithm, with the branch metric at time $k$:

$$\lambda_k = -\frac{1}{2\sigma^2} \sum_{j=1}^{D} |r_k^j - a_k S_k^j|^2 + L_a(S_k)$$

$$j = 1, 2, \ldots, D$$

(3)

where $L_a(S_k)$ is the a priori likelihood value of the current signal $S_k$. The $r_k^j$ and $S_k^j$ are the $D$-dimensional received and transmitted signals at time $k$, respectively. The $a_k$ represents the information of the fading channel, and $\sigma^2$ is the variance of the additive noise. The systematic and extrinsic information extracted from the signal vector is exchanged between the two decoders iteratively. In Figure 2, the $L_{1s&e}$ and $L_{2s&e}$ denote the respective systematic and extrinsic information from DEC1 and DEC2.

The design of TCM/MPSK scheme for fading channel has been studied in depth and the optimum TCM codes have been exhaustively investigated in [3]-[5]. Here, these optimum TCM codes are employed for Turbo TCM/FPM scheme. The minimum squared Euclidean distance versus $h$ is shown in Figure. 3. It is observed that for a given value of $h$, the distance depends on $\phi$. This implies that Turbo TCM/FPM scheme is likely to be optimized by varying $\phi$.

### 3. SIMULATION RESULT

The performance of Turbo TCM/FPM in a DS/SSMA system over a multipath Rician fading channel was simulated. The DS/SSMA system has 20 users and a spreading sequence length of 511. Multiple access interference is approximated as a Gaussian distributed random variable. The Rician parameter of the fading channel is set to 6. The channel code of each user is composed of 2 identical eight-state recursive systematic TCM code with the parity check polynomials (in octal form) $PCP=[11_0, 05_0, 13_0]$ which is optimum for fading channel [3]-[5]. The data frame size is set to 200 as is typical in packet radio systems and eight iterations, wherever applicable, for all cases are set. For comparisons with Turbo TCM 8PSK and TCM/FPM schemes, we use the 99 percent bandwidth mentioned in the previous section. The bit error rate (BER) performance in a DS/SSMA system over multipath Rician fading channel is shown in Figure 4. The dotted curve shows the performance using TCM/FPM scheme at $h=0.5$, $\phi=0$. The dashed-dotted curve shows the performance using Turbo TCM 8PSK scheme. The solid curves show the performance using the proposed Turbo TCM/FPM scheme with different $h$ and $\phi$. The most significant gain occurs when $h$ reaches to 1.0, that is the high modulation index outperforms the lower one. While for a given $h=0.5$, the case $\phi=\pi/4$ is better than $\phi=0$. This coincides with the observation in Figure 3. An improvement of 2dB can be achieved at BER=10^{-3} for Turbo TCM/FPM with $h=0.5$, $\phi=0$ as compared with Turbo TCM 8PSK. This result shows that the four-dimensional coded 2FSK/4PSK modulation increases the distance spectrum of the signal without sacrificing the power and bandwidth efficiency. Similarly, a significant improvement of 4.5dB can be obtained when it is compared with TCM/FPM with $h=0.5$, $\phi=0$.

### 4. CONCLUSIONS

Turbo TCM/FPM scheme can achieve considerable coding gain over the Turbo TCM 8PSK and conventional TCM/FPM schemes without sacrificing the power and bandwidth efficiency. The performance of Turbo TCM/FPM in a DS/SSMA system improves significantly over a multipath Rician fading channel. This scheme is attractive for the power-limited and band-limited environment.

### REFERENCES


Figure. 1 Block diagram of Turbo TCM/FPM scheme in a DS/SSMA system

Figure. 2 The 2FSK/4PSK signal constellation with twisted angle $\phi$

$$f_1 = f_c + h/2T$$

$$f_2 = f_c - h/2T$$
Figure. 3 Minimum squared Euclidean distance versus $\phi$ for different $h$

Figure. 4 BER versus $E_b/N_0$ of Turbo TCM/FPM scheme in a DS/SSMA system over multipath Rician fading channel