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트렐리스 부호화된 MDPSK의 흐름 다중심볼 차동검파

(Sliding Multiple Symbol Differential Detection of Trellis-coded MDPSK)

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要 約

본 논문에서는 2/4 MTCM된 $\Pi/4$ shigt QPSK, 4/6 MTCM된 8DPSK, 6/8 MTCM된 16DPSK에 다중심볼 차동검파를 적용하여 오류성능을 향상시키기 위한 방법을 제시한다. 두가지 형태의 흐름 다중심볼 차동검파 알고리듬을 제안하고(Type 1, Type 2), AWGN 환경에서 Monte Carlo 시뮬레이션을 사용하여 심볼당 차동검파 방식과 블럭 검파 방식과 비교를 행한다. 시뮬레이션을 통하여 제안된 두가지 알고리듬의 성능은 심볼당 차동검파 방식과 블럭 검파 방식에 비하여 성능이 향상됨을 보인다. 시뮬레이션은 상태수가 2, 4, 8인 경우에 대하여 수행하였다.

Abstract

In this paper, the idea of using a multiple symbol obervation interval to improve error probability performance is applied to differential detection of MTCM(multiple trellis code modulation) with $\Pi/4$ shift QPSK, 8DPSK and 16DPSK. We propose two types of sliding multiple symbol differential detection algorithm, type 1 and type 2. The two types of sliding detection scheme are examined and compared with conventional(symbol-by-symbol) detection and block detection with these modulation formats in an additive white Gaussian noise(AWGN) using the Monte Carlo simulation. We show that the amount of improvement over conventional and block detection depends on the number of phases and the number of additional symbol intervals added to the observation. Computer simulation results are presented for 2,4,8 states in AWGN channel.

I. INTRODUCTION

Trellis coded modulation(TCM) has received much attention for bandwidth and power efficient transmission of data. It has been used in various applications including voiceband modems, satellite communications and magnetic recording. Since its introduction, many papers have investigated various applications and properties of trellis coded modulation.[4][5] Multiple TCM(MTCM) schemes have been proposed to improve coding gains on the AWGN and fading channels.[6]

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In a previous paper [1], the notion of using a multiple symbol observation interval for differentially detecting uncoded multiple phase-shift-keying(MPSK) was introduced. This technique made use of the maximum-likelihood sequence estimation of N-1(N>2) phases rather than the symbol-by-symbol detection as in conventional (N=2) differential detection.

In [2], this idea was extended to trellis coded modulation, in particular, MPSK. Therefore, it was shown that a combination of MTCM with multiplicity(number of trellis code output symbols per input symbol) equal to N-1 combined with a multiple symbol differential detection scheme can yield a significant improvement in performance. For this kind of detection scheme the equivalent Euclidean distance(ED) measure per trellis branch is determined and under each trellis branch there are N sequences being block processed.

In this paper, we propose two types of sliding multiple symbol detection that make use of the block detection per each signal on trellis branch. For these kinds of detection scheme, decoding metric is defined. It is shown that sliding detection schemes will provide a significant improvement in bit error probability performance rather than conventional and block detection scheme in AWGN through the use of computer simulations.

Ⅱ. SYSTEM MODEL

Figure 1 is a simplified block diagram of the system under investigation. Input bits occurring at a rate R_b are passed through a rate $nk/(n+1)k$ multiple trellis encoder producing an encoded bits stream at a rate $R_s = [(n+1)k/nk]\ R_b$. Next, the encoded bits are divided into k=2(k is the multiplicity of the code) groups. Each group is mapped into a symbol selected from an M level PSK signal set according to a optimum set partitioning method for multiple trellis codes in AWGN channel. For the 2/4 MTCM with $\Pi/4$ shift QPSK, 4/6 MTCM with 8DPSK and 6/8 MTCM with 16DPSK, M level is 4, 8 and 16, respectively. So, each MTCM scheme is unity bandwidth expansion relative to an uncoded DPSK, DQPSK and 8DPSK. Then M level PSK symbols are then differentially encoded every T_s and modulated onto an RF carrier for transmission over the channel

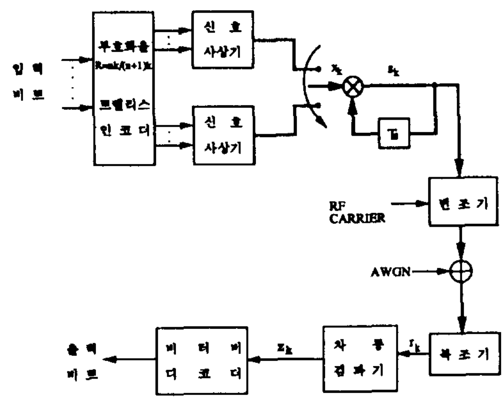


Fig. 1. System Block Diagram of MTCM with multiplicity=2.

At the receiver, the noise-corrupted signal is differentially detected and the resulting symbols are then fed into the trellis decoder which is implemented with the Viterbi algorithm. For conventional differential detection, symbol-by-symbol detection is used and for block multiple symbol detection, equivalent symbol trellis code is determined. For sliding multiple symbol detection, two types of decoding metric are proposed, and we call each type type 1 and type 2.

Ⅲ. ANALYSIS MODEL

We denote a coded symbol sequence of length N_s by

$$\underline{x} = (x_1, x_2, \cdots, xN_s) \quad (1)$$

where the kth element of $\underline{x}$, namely, x_k represents the transmitted MPSK symbol in the kth transmission interval, and in general, is a nonlinear function of the state of the encoder and the nk information bits at its input. Before transmission over the channel, the sequence $\underline{x}$ is differentially encoded, producing the sequence $\underline{s}$. In phasor notation, s_{k-1} and s_k can be written as

$$s_{k-1} = \sqrt{2P}e^{j\phi_{k-1}}$$
$$s_k = s_{k-1}x_k = \sqrt{2P}e^{j(\phi_{k-1}+\Delta\phi_k)} = \sqrt{2P}e^{j\phi_k} \tag{2}$$

where $E_s=rE_b$ is the energy per MDPSK symbol, r is a throughput, and

$$x_k = e^{j\Delta\phi_k} \tag{3}$$

is the phasor representation of MPSK symbol $\triangle\phi_k$ assigned by the mapper in the kth transmission interval.
The corresponding received signal in the kth transmission interval is

$$r_k = s_k e^{j\theta_k} + n_k \tag{4}$$

where n_k is a sample of zero mean complex Gaussian noise with variance(per dimension)

$$\sigma_n^2 = \frac{N_0}{T} \tag{5}$$

and θ_k is an arbitrary phase introduced by channel which is assumed to be uniformly distributed in the interval $(-\Pi, \Pi)$. In [1] it was shown that for uncoded MPSK the maximum-likelihood decision statistic based on an observation of N successive MPSK symbols is

$$\eta = \left| r_{k-N+1} + \sum_{n=0}^{N-2} r_{k-n} e^{-j\sum_{m=0}^{N-n-2}\Delta\phi_{k-n-m}} \right|^2 \tag{6}$$

Since the first phase in this sequence acts as the reference phase, this statistic allows a simultaneous decision to be made on N-1 phases in accordance with the particular data phase sequence $\triangle\phi_{k-N-2}$, $\triangle\phi_{k-N-1}$, ⋯, $\triangle\phi_k$ that maximizes η.

In [2], in order to make use of the idea of multiple differential detection to the trellis coded MPSK, a multiple trellis code with multiplicity k=N-1 was introduced. This partitioned the transmitted sequence of (1) into subsequences of block $B=N_s/k=N_s/(N-1)$.

$$\underline{x} = \left(x^{(1)}, x^{(2)}, \cdots, x^{(B)}\right) \tag{7}$$

with each subsequence $x^{(i)}=(x_{i_1}, x_{i_2}, \cdots, x_{i_k})$ representing an assignment to the trellis branch. Similarly, a received sequence r of length N_s is associated with a path of length B branches in the diagram. On an additive white Gaussian noise(AWGN) channel, it has been shown [2] that the pairwise error probability is given by

$$P(\underline{x} \rightarrow \hat{\underline{x}}) \le \prod_{\Delta\hat{\phi}^{(i)} \ne \Delta\phi^{(i)}}^{B} \frac{\exp\left\{ \frac{E_s}{N_0} \frac{\lambda(1-\lambda)\left[N^2 - |\delta_i|^2\right]}{1-\lambda^2\left[N^2-|\delta_i|^2\right]} \right\}}{1-\lambda^2\left[N^2-|\delta_i|^2\right]} \tag{8}$$

where

$$\delta_i = \sum_{n=0}^{N} \exp\left(j\sum_{m=0}^{N-n-2} \left(\Delta\Phi_{k-n-m}^{(i)} - \Delta\hat{\Phi}_{k-n-m}^{(i)} \right) \right) \tag{9}$$

The total metric proposed for the multiple trellis decoder with channel state information is

$$\eta = \sum_{i=1}^{B} \left| r_{k-N+1}^{(i)} + \sum_{n=0}^{N-2} r_{k-n}^{(i)} e^{-j\sum_{m=0}^{N-n-2}\Delta\phi_{k-n-m}^{(i)}} \right|^2 \tag{10}$$

For the case of N=3

$$\begin{aligned}
\eta &= \sum_{i=1}^{B} \left| r_{k-2}^{(i)} + r_{k-1}^{(i)} x_{k-1}^{*(i)} + r_k^{(i)} x_k^{*(i)} x_{k-1}^{*(i)} \right|^2 \\
&= \sum_{i=1}^{B} \left[3 + 2\,\mathrm{Re}\left\{ x_{k-1}^{(i)} \hat{x}_{k-1}^{*(i)} \right\} + 2\,\mathrm{Re}\left\{ x_k^{(i)} \hat{x}_k^{*(i)} \right\} + 2\,\mathrm{Re}\left\{ x_k^{(i)} \hat{x}_k^{*(i)} x_{k-1}^{(i)} \hat{x}_{k-1}^{*(i)} \right\} \right] \\
&= \sum_{i=1}^{B} \left\{ 9 - \left| x_k^{(i)} \hat{x}_k^{(i)} \right|^2 - \left| x_{k-1}^{(i)} \hat{x}_{k-1}^{(i)} \right|^2 - \left| x_k^{(i)} x_{k-1}^{(i)} \hat{x}_k^{(i)} \hat{x}_{k-1}^{(i)} \right|^2 \right\} \\
&= \sum_{i=1}^{B} l^{(i)}
\end{aligned} \tag{11}$$

where

$$l^{(i)} = 9 - \left| x_k^{(i)} - \hat{x}_k^{(i)} \right|^2 - \left| x_{k-1}^{(i)} - \hat{x}_{k-1}^{(i)} \right|^2 - \left| x_k^{(i)} x_{k-1}^{(i)} - \hat{x}_k^{(i)} \hat{x}_{k-1}^{(i)} \right|^2 \tag{12}$$

To obtain a sequence with I^{η} at a maximum, we must minimize the following metric.

$$metric = \left|x_k^{(i)} - \hat{x}_k^{(i)}\right|^2 + \left|x_{k-1}^{(i)} - \hat{x}_{k-1}^{(i)}\right|^2 + \left|x_k^{(i)} x_{k-1}^{(i)} - \hat{x}_k^{(i)} \hat{x}_{k-1}^{(i)}\right|^2 \quad (13)$$

Observing (13), we can perceive a block processing technique which processes the sequence in blocks. Figure 2 shows the block diagram of the receiver pertaining to (13). (10) maximizes η through block processing using the first term as a reference phase. The first two terms in (13) shows the squared-Euclidean distance related to the two symbols that are assigned to the ith trellis branch. The third term is a virtual symbol which correspondsto the modulo M sum of the first two symbols in each branch. Because the virtual symbol corresponds to the term obtained from the process of multiple symbol differential detection as shown in Figure 2, the metric of (13) can be seen as a MTCM with a multiplicity of 3.

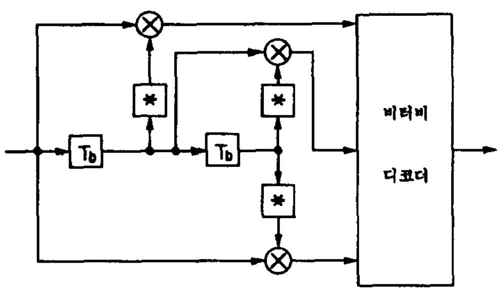


Fig. 2. Demodulation Block Diagram with Block Detection Scheme.

In the case of the conventional symbol-by-symbol differential detection, each differential decoded symbol is inputted to the Viterbi decoder, and for the case of the multiple symbol differential detection, not only is the symbols assigned to the trellis branch but also the additional symbol is seen to be inputted to the Viterbi decoder. Now we consider the sliding multiple symbol differential detection(SMSDD) method which combines the above conventional differential detection with the multiple symbol differential detection(MSDD) for each symbol assigned to the signal of the ith multiple trellis branch. Hence, the Sliding multiple symbol differential detection method can be interpreted as a process which executes the multiple symbol differential detection for wach symbol that is assigned to the ith multiple symbol branch.

Though, let's consider sliding processing using the previous two phases as a reference with N=3. Total metic becomes

$$\begin{aligned}
\eta &= \sum_{i=1}^{N_s}\left\{\left|r_{k-2} + r_k e^{-j(\Delta\phi_k + \Delta\phi_{k-1})}\right|^2 + \left|r_{k-1} + r_k e^{-j\Delta\phi_k}\right|^2\right\} \\
&= \sum_{i=1}^{N_s}\left\{\left|r_{k-2} + r_k x_k^* x_{k-1}^*\right|^2 + \left|r_{k-2} + r_k x_k^*\right|^2\right\} \\
&= \sum_{i=1}^{N_s}\left[4 + 2\,\mathrm{Re}\left\{x_k \hat{x}_k^*\right\} + 2\,\mathrm{Re}\left\{x_k \hat{x}_k^* x_{k-1} \hat{x}_{k-1}^*\right\}\right] \\
&= \sum_{i=1}^{N_s}\left\{8 - \left|x_k - \hat{x}_k\right|^2 - \left|x_k x_{k-1} - \hat{x}_k \hat{x}_{k-1}\right|^2\right\} \quad (14)
\end{aligned}$$

To find the symbol sequence with η at a maximum, we must minimize the following metric

$$metric = \left|x_k - \hat{x}_k\right|^2 + \left|x_k x_{k-1} - \hat{x}_k \hat{x}_{k-1}\right|^2 \quad (15)$$

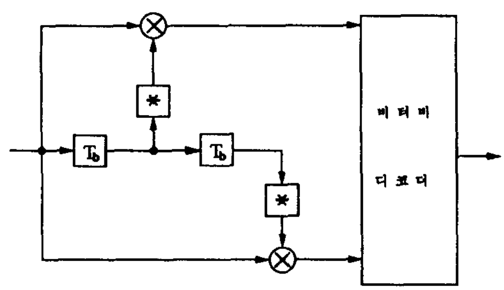


Fig. 3. Demodulation Block Diagram with Type 1 Sliding Detection Scheme.

Figure 3 shows the block disgram of a receiver performing (15). If processing as shown above is done at each received signal, two error-free signals will exist at each branch, which then allows us to transform the format to that of block processing at each signal. If the first signal was received at the ith block. (15) becomes :

$$metric_1 = \left|x_1^{(i)} - \hat{x}_1^{(i)}\right|^2 + \left|x_1^{(i)} x_2^{(i-1)} - \hat{x}_1^{(i)} \hat{x}_2^{(i-1)}\right|^2 \quad (16)$$

When the second signal is received at the ith block :

$$metric_2 = \left|x_2^{(i)} - \hat{x}_2^{(i)}\right|^2 + \left|x_1^{(i)} x_2^{(i)} - \hat{x}_1^{(i)} \hat{x}_2^{(i)}\right|^2 \quad (17)$$

From (16) and (17), metric becomes :

$$\begin{aligned} metric &= metric_1 + metric_2 \\ &= \left|x_1^{(i)} - \hat{x}_1^{(i)}\right|^2 + \left|x_1^{(i)} x_2^{(i)} - \hat{x}_1^{(i)} \hat{x}_2^{(i)}\right|^2 \\ &+ \left|x_2^{(i)} - \hat{x}_2^{(i)}\right|^2 + \left|x_1^{(i)} x_2^{(i-1)} - \hat{x}_1^{(i)} \hat{x}_2^{(i-1)}\right|^2 \quad (18) \end{aligned}$$

The first three terms in (18) shows the squared Euclidean that is the same as (13) assigned to the ith trellis branch, while the fourth term shows the additional symbol that corresponds to the modulo M sum of the second symbol assigned to the (i-1)th trellis branch and the first symbol pertaining to the ith trellis branch. Therefore the Type 1 sliding multiple symbol differential detection method can be considered as a MTCM with a multiplicity 4 seen in (18). Thus, the Viterbi decoder, after receiving the first signal at the ith block, calculates a temporary metric with the second signal of the previous block, and then after receiving the second signal, calculates the entire path metric. Figure 4 shows the block diagram of a receiver when the sliding processing of type 1 is analyzed through block processing.

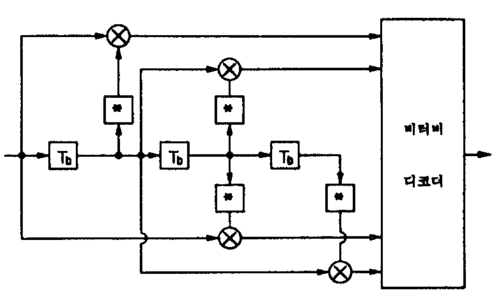


Fig. 4. Demodulation Block Diagram when the Type 1 Sliding Processing is analyzed through Block Processing.

Figure 5 shows the procedure of calculating the metric with respect to a 2 state. The sequence of the algorithm calculating the metric is as follows.

step 1: If the input signal corresponding to the first signal at the ith block enters the Viterbi decoder, this signal combines with the second signal at the (i-1)th block of each state, obtaining a temporary branch metric according to (16).

step 2: If the signal corresponding to the second signal of the ith block is inputted, this combines with the first signal of the ith block, and then a branch metric according to (17) is formulated.

step 3: From the metric obtained from step 1 and step 2, the path metric is calculated.

step 4: Before the signal of the (i+1) block is received, the value of the path metric is compared, choosing the survival path.

step 5: Each time the signal is inputted into the Viterbi decoder, the above steps are repeated , and the information data is decoded.

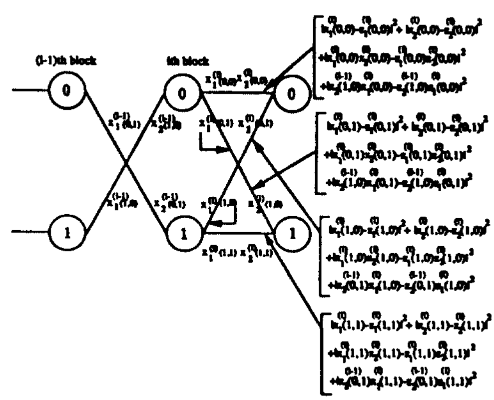


Fig. 5. Procedure of Calculating the metric of Type 1 Scheme.

The sliding scheme of type 2 is illustrated in Figure 6 where type 1 scheme is also contained for comparision. The total metric of type 2 sliding scheme is calculated as follows.

$$metric = \left|x_1^{(i)} - \hat{x}_1^{(i)}\right|^2 + \left|x_1^{(i)}x_2^{(i-1)} - \hat{x}_1^{(i)}\hat{x}_2^{(i-1)}\right|^2$$
$$+ \left|x_1^{(i)} - x_2^{(i-1)}x_1^{(i-1)} - \hat{x}_1^{(i)}\hat{x}_2^{(i-1)}\hat{x}_1^{(i-1)}\right|^2$$
$$+ \left|x_2^{(i)} - \hat{x}_2^{(i)}\right|^2 + \left|x_1^{(i)}x_2^{(i)} - \hat{x}_1^{(i)}\hat{x}_2^{(i)}\right|^2$$
$$+ \left|x_1^{(i)} - x_2^{(i)}x_2^{(i-1)} - \hat{x}_1^{(i)}\hat{x}_2^{(i)}\hat{x}_2^{(i-1)}\right|^2 \quad (19)$$

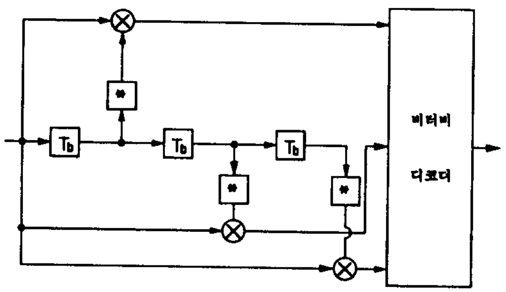


Fig. 6. Type 2 Sliding Detection Scheme.

Eventually, it can be considered in this paper that, for the case when the multiplicity is 2, the type 1 scheme can be considered as a MTCM of multiplicity of 4, and the type 2 scheme can be regarded as a MTCM having a multiplicity of 6.

Ⅳ. SIMULATION RESULTS

In this section, we describe and present the results of a computer simulation of the various differential detection methods of MTCM with $\Pi/4$ shift QPSK, 8DPSK and 16DPSK. The performance improvement of sliding multiple symbol differential detection method is checked through the computer simulation based on the Monte Carlo method. It is assumed that the transmitted signal is corrupted by AWGN. We perform the computer simulation for 2,4,8 states with above modulation formats. The length of the path memory in the Viterbi decoding algorithm is M=5v(M:decision delay, v:state number).

The results of the simulations for $\Pi/4$ shift QPSK are shown in Figure 7. At the 10^{-5} BER for data transmission, the sliding detection methods are nearly the same performance as other detection methods. For 8DPSK in Figure 8, type 1 sliding detection method demonstrates an improvement of 1.0 - 2.0dB over other schemes. We observe from these figures that an improvement in E_b/N_o performance of type 2 sliding scheme when compared with the type 1 scheme is obtained. Figure 9 and 10 show the performance improvement of 4/6 MTCM with Type 1 and Type 2 sliding multiple symbol differential detection over the uncoded DQPSK according to the state variation. The results for 6/8 MTCM with 16DPSK are shown in Figure 11. Figure 12 and 13 show the performance improvement of 6/8 MTCM with Type 1 and Type 2 sliding multiple symbol differential detection over the uncoded 8DPSK according to the state variation.

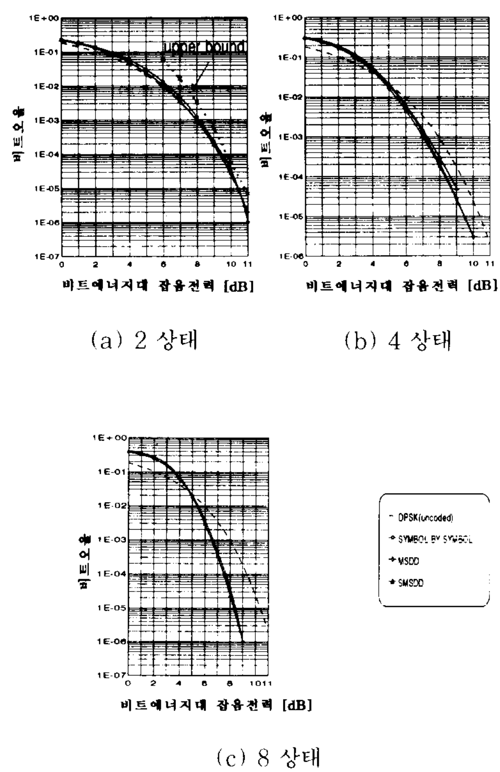
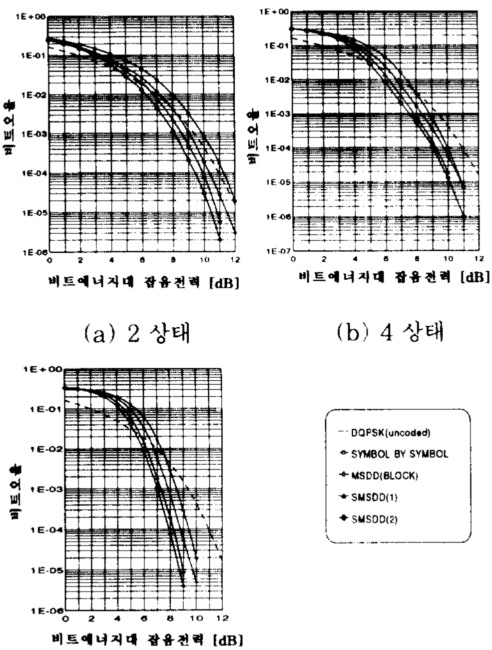


Fig. 7. BER Performance of 2/4 MTCM using $\Pi/4$ shift QPSK.



(a) 2 상태 (b) 4 상태

(c) 8 상태

Fig. 8. BER Performance of 4/6 MTCM using 8DPSK.

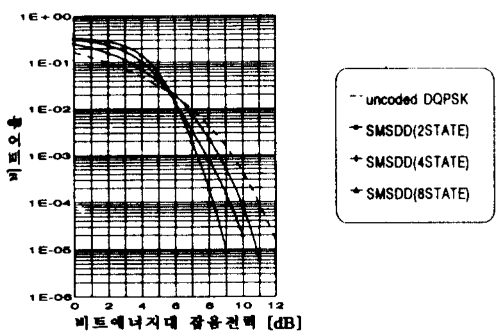


Fig. 9. BER Performance of 4/6 MTCM with TYPE 1 method.

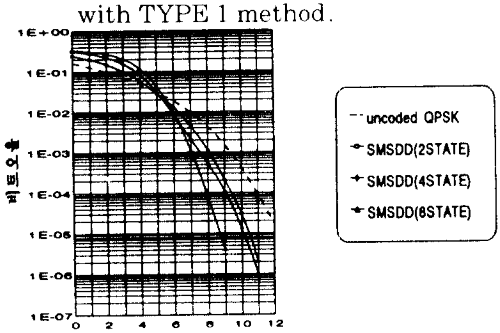
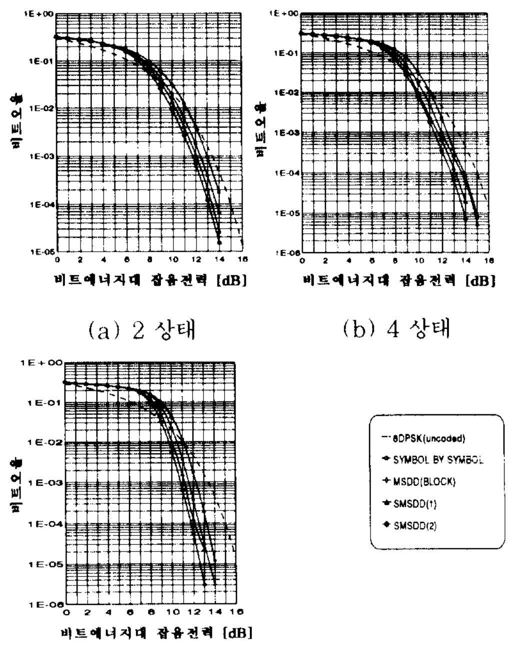


Fig. 10. BER Performance of 4/6 MTCM with TYPE 2 method.



(a) 2 상태 (b) 4 상태

(c) 8 상태

Fig. 11. BER Performance of 6/8 MTCM using 16DPSK.

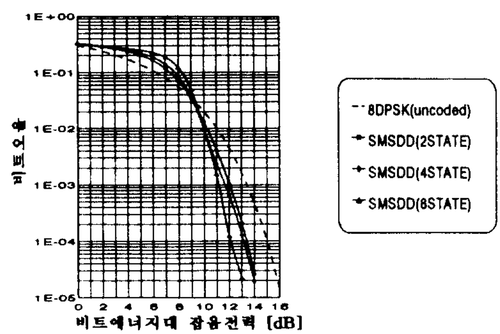


Fig. 12. BER Performance of 6/8 MTCM with TYPE 1 method.

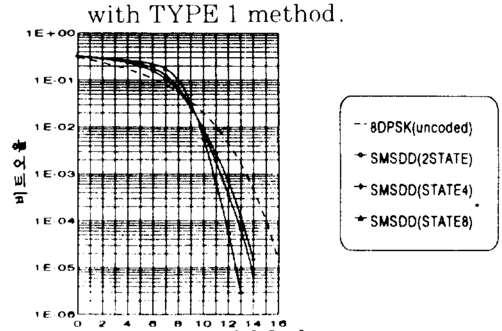


Fig. 13. BER Performance of 6/8 MTCM with TYPE 2 method.

V. CONCLUSIONS

We have presented two types of sliding multiple symbol differential detection of MTCM and have defined the decoding metric for each sliding methods. The use of sliding multiple symbol differential detection of trellis coded MDPSK can offer an improvement in error probability performance over conventional and block differential detection of the same coded modulation. It has been shown that sliding multiple symbol differential detection of 2/4 MTCM using $\Pi/4$ shift QPSK, 4/6 MTCM using 8DPSK and 6/8 MTCM using 16DPSK will provide a significant improvement in BER performance rather than symbol-by-symbol detection and block detection schemes. We have demonstrated that the amount of improvement depends on the number of phases and the additional symbol intervals added to the observation.

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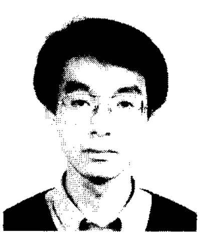

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