Research Article
Joint Decoding of Concatenated VLEC and STTC System

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Received 1 November 2007; Revised 26 March 2008; Accepted 6 May 2008

Recommended by Jinhong Yuan

We consider the decoding of wireless communication systems with both source coding in the application layer and channel coding in the physical layer for high-performance transmission over fading channels. Variable length error correcting codes (VLECs) and space time trellis codes (STTCs) are used to provide bandwidth efficient data compression as well as coding and diversity gains. At the receiver, an iterative joint source and space time decoding scheme are developed to utilize redundancy in both STTC and VLEC to improve overall decoding performance. Issues such as the inseparable systematic information in the symbol level, the asymmetric trellis structure of VLEC, and information exchange between bit and symbol domains have been considered in the maximum a posteriori probability (MAP) decoding algorithm. Simulation results indicate that the developed joint decoding scheme achieves a significant decoding gain over the separate decoding in fading channels, whether or not the channel information is perfectly known at the receiver. Furthermore, how rate allocation between STTC and VLEC affects the performance of the joint source and space-time decoder is investigated. Different systems with a fixed overall information rate are studied. It is shown that for a system with more redundancy dedicated to the source code and a higher order modulation of STTC, the joint decoding yields better performance, though with increased complexity.

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1. INTRODUCTION

Providing multimedia service has become an attractive application in wireless communication systems. Due to bandwidth limitation and harsh wireless channel conditions, reliable source transmission over wireless channel remains a challenging problem. Space time code and variable length source code are two key enabling techniques in the physical and application layers, respectively.

Tarokh introduced space time trellis codes (STTCs) [1] in multiple-input multiple-output (MIMO) systems, which obtain bandwidth efficiency four times higher than diversity systems without space time coding. While these STTCs are designed to achieve the maximum diversity in space dimension, the coding gain in time dimension, on the other hand, still may be improved.

Variable length error correcting codes (VLECs) [2] are a family of error correcting codes used in source coding. VLEC maps source symbols to codewords of variable length according to the source statistics. Compared to Huffman code aiming for high-compression efficiency, VLEC has inherent redundancy and some error resilient capability. However, VLEC is still sensitive to channel errors and one single bit error may cause continuous source symbol partition errors due to the well-known synchronization problem.

Shannon’s classical separation theory states that we can optimize the system by designing optimal source code and channel code separately. However, this theorem holds only for infinite size of packets. Therefore, with delay and computation resource constraint, joint optimization of source and channel coding or decoding often yields better performance in realistic systems. Joint source channel decoding (JSCD) basically focuses on using the redundancy in the source coded stream to improve the overall decoding performance. Constraint JSCD (C-JSCD) is discussed in [3, 4], in which the output from channel decoder is modeled as an output from binary symmetric channel (BSC) and the source decoder exploits the statistic character of BSC as a constraint in the maximum a posteriori probability (MAP) algorithm. Integrated JSCD (I-JSCD), proposed in [5, 6], merges the trellises of source code and channel code into one integrated trellis and carries out MAP decoding based on the combined trellis. The drawback of I-JSCD is that the decoding complexity dramatically increases with the number of states in the combined trellis. Recently, iterative JSCD
[7, 8] adopts iterative decoding structure and information exchange between source decoder and channel decoder. It has attracted increasing attention because of its relatively low decoding complexity.

Joint decoding schemes with space time components have also been considered recently. A mega concatenation system of multiple-level code, trellis-coded modulation (TCM), and STTC is proposed in [9] to provide unequal error protection for MPEG4 streams. Variable length space-time-coded modulation (VL-STCM) is proposed in [10, 11] by concatenating VLC and BLAST in MIMO systems. Iterative detection structure is proposed in [12] for a concatenated system with reversible variable length code (RVLC), TCM, and diagonal block space time trellis code (DBSTTC). In this paper, we consider another type of systems where recursive STTCs (Rec-STTCs) with full transmit diversity gain and some coding gain are concatenated with source VLECs. For this type of systems, we design an iterative decoding scheme to fully utilize the redundancy in both source code and space time code. Modification of MAP decoding algorithms and information exchange between symbol and bit domains from the two component decoders are addressed. This iterative decoding is evaluated in both quasi static and rapid fading channels when either perfect channel information is available or the channel estimation errors exist. The results show significant decoding gain over noniterative decoding in the tested cases. Furthermore, we study the rate allocation issue dealing with how to allocate the redundancy between STTC and VLEC for better decoding performance under the overall bandwidth and transmission power constraint. We find that with increased decoding complexity, the joint decoding system performance can be improved by introducing more redundancy into source code while using a higher-order modulation in STTC.

The rest of paper is organized as follows. The concatenation structure of VLEC and STTC is described in Section 2. Joint source and space time decoding algorithm is discussed in Section 3 in detail. Performance in case of perfect channel estimation is provided in Section 4. Performance in presence of channel estimation errors is presented in Section 5. The rate allocation issue is then investigated in Section 6. Finally, conclusions are drawn in Section 7.

2. SYSTEM WITH VLEC AND STTC

The encoder block diagram is depicted in Figure 1. We assume $a_i, i = 0, 1, \ldots, K - 1$ is one packet of digital source symbols, drawn from a finite alphabet set $0, 1, \ldots, N - 1$. $K$ is the packet length, $N$ is the source alphabet size. The VLEC encoder maps each source symbol to a variable length codeword at a code rate $R_{VLEC} = \frac{H}{l}$. $H$ is the average VLEC codeword length. $l$ is the entropy of the source. The generated bit sequence is $b_j, j = 0, 1, \ldots, L - 1$. A bit interleaver is inserted before the use of STTC for time diversity. In this paper, we use a random interleaver.

Consider $2^p$-ary modulation is used, the bit stream is grouped every $p$ bits and converted to symbol stream $c_t, t = 0, 1, \ldots, \lfloor L/p \rfloor - 1$ as the input to STTC encoder. The output from STTC is $N_T$ modulated symbol sequences

![Figure 1: Serial concatenation of VLEC and STTC.](image)

| Table 1: Examples of VLEC [8]. |
|---------------------------------|
| Symbol | Probability | Huffman | C1 | C2 |
| 0      | 0.33        | 00      | 00 | 11 |
| 1      | 0.3         | 11      | 11 | 001 |
| 2      | 0.18        | 10      | 101 | 0100 |
| 3      | 0.1         | 010     | 010 | 001100 |
| 4      | 0.09        | 011     | 0110 | 0001010 |

$E[l] = H = 2.14$, $d_f = 1.29$, $d_i = 2.46$, $d_{ij} = 3.61$

$\eta_j$ is the additive complex white Gaussian noise on the $j$th receive antenna at time $t$ with zero mean and variance of $N_0/2$ per dimension.

2.1. Variable length error correcting code

In [2], Buttigieg introduced variable length error correcting code (VLEC). It is similar to block error correcting code in that each source symbol is mapped to a codeword, but with different length. The more frequent symbols are assigned with shorter codewords. The codewords are designed so that a minimum free distance is guaranteed. With a larger free distance, VLEC has stronger error resilience capability. However, in the mean time, more redundancy is introduced and the average length per symbol increases, which reduces the overall effective information rate. Table 1 gives the examples of Huffman code and two VLECs of a same source with different free distances from [8].

Since a bit-based trellis representation was proposed for VLEC [13], the MAP decoding algorithm can also be adopted for bit-level VLEC decoding. Figure 2 gives the tree structure and the bit-level trellis representation of VLEC C1.
convolutional codes have been presented in [14, 15]. In both cases, recursive convolutional code is required.

The branches in the trellis describe the state transitions at terminal nodes and denoted by the “T” states in the trellis. The branches in the trellis describe the state transitions at any bit instance along the source coded sequence.

### 2.2. Recursive space time trellis code

The recursive nature of component encoders is critical to the excellent decoding performance of turbo codes. General rules for designing parallel and serial concatenated convolutional codes have been presented in [14, 15]. In both cases, recursive convolutional code is required.

In [16], Tujkovic proposed recursive space time trellis code (Rec-STTC) with full diversity gain for parallel concatenated space time code. Figure 3 gives the example of Rec-STTCs in [16] for two transmit antennas. The upper part is a 4-state, QPSK modulated Rec-STTC (ST1) with bandwidth efficiency 2 bit/s/Hz and the lower part is an 8-state, 8PSK modulated Rec-STTC (ST2) with bandwidth efficiency 3 bit/s/Hz. Each line represents a transition from the current state to the next state. The numbers on the left and right sides of the dashes are the corresponding input symbols and two output symbols, respectively.

### 3. JOINT VLEC AND SPACE TIME DECODER

Consider the above serial concatenated source and space time coding system. Conventionally, the separate decoding stops after one round of STTC decoding followed by VLEC decoding. In this paper, we utilize both redundancy in VLEC and error correcting ability of STTC in time dimension to facilitate each other’s decoding through an iterative process, and hence to improve the overall decoding performance.

Figure 4 illustrates the iterative joint source and space time decoding structure. Assume that the packet has been synchronized and the side information of the packet length in bit after VLEC encoder is known at the receiver. Soft-input soft-output MAP algorithm [17] is used in both VLEC and STTC decoders.

#### 3.1. MAP in symbol and bit domains

The MAP decoder takes the received sequences as soft inputs and a priori probability sequences and outputs an optimal estimate of each symbol (or bit) in the sense of maximizing its a posteriori probability. The a posteriori probability is calculated through the coding constraints represented distinctly by trellis.

Given the received streams,

\[
r = \begin{bmatrix} r_0^0, & \ldots, & r_0^j, & \ldots \end{bmatrix},
\]

and assume perfect channel information \( f = [f_t^{i,j}], i = 0, \ldots, N_R - 1, j = 0, \ldots, N_T - 1 \), known at the receiver, at each time index \( t \), then the space time decoder generates symbol domain log-likelihood values for all symbols in the signal constellation \( Q = q, q = 0, 2^l - 1 \) as follows:

\[
L(\tilde{c}_t = q | r) = \ln \sum_{(s',s) = q} \alpha_{t-1}(s') \gamma_t(s',s) \beta_t(s),
\]

where \((s',s)\) represents the state transition from time \( t - 1 \) to time \( t \) on the STTC trellis,

\[
\gamma_t(s',s) = P(r_t | (s',s)) P(s|s').
\]

and

\[
\ln P(r_t | (s',s)) = -C \sum_{j=0}^{N_R - 1} \sum_{i=0}^{N_T - 1} d_{ji}^t \left| r_t^j - f_{t}^{i,j} \right|^2,
\]

where \( d_{ji} \) are the transmitted signals associated with transition branch \((s',s)\) at time \( t \). C is a constant that depends on the channel condition at time \( t \) and is the same for all possible transition branches. \( P(s|s') \) is a
priori information and equal to $P(q : (s', s) \rightarrow q)$. Without any a priori information, every symbol in constellation is considered as generated with equal possibility and $P(s|s')$ is set to $1/2^R$.

$\alpha_i(s)$ is the probability that the state at time $t$ is $s$ and the received signal sequences up to time $t$ are $r_{k:t+1}$. It can be calculated by a forward pass as

$$\alpha_i(s) = \sum_{s'} \gamma_i(s', s) \alpha_{i-1}(s'). \quad (6)$$

$\beta_{i-1}(s')$ is the probability that the state at time $t-1$ is $s'$ and the received data sequences after time $t-1$ are $r_{k:t-1}$, and can be calculated by a backward pass as

$$\beta_{i-1}(s') = \sum_s \beta_i(s) \gamma_i(s', s). \quad (7)$$

The initial values $a_0(0) = \beta_0(0) = 0$ ($Ns$ is the packet length in modulated symbol), assuming tail symbols are added to force the encoder registers back to the zero state.

It needs to be pointed out that $L(\hat{c}_i = q | r)$ in (3) is a log-likelihood value but not the log-likelihood ratio in the conventional MAP decoding. This is because multiple candidate symbols exist in the STTC constellation. Besides, the systematic and parity information can no longer be separated in (5), because the two output symbols in any trellis transition are sent through two transmit antennas simultaneously. Received signal on any receive antenna is an additive effect of two symbols and the noise. Equation (3) can be rewritten as

$$L(\hat{c}_i = q | r) = L_{a,STTC} + L_{e,STTC}, \quad (8)$$

where

$$L_{a,STTC} = \ln P(\hat{c}_i = q),$$

$$L_{e,STTC} = \ln \sum_{(r', s') \rightarrow q} \alpha_{i-1}(s') P(r_i | (s', s)) \beta_i(s). \quad (9)$$

As a result, each symbol domain log-likelihood value comprises only two parts: extrinsic information and a priori information. The extrinsic information of STTC will be sent to the VLEC decoder as a priori information.

The bit-indexed soft input sequence $Y$ to VLEC decoder is the extrinsic information from the channel decoder in the first iteration. VLEC MAP decoder calculates bit domain log-likelihood ratio for each coded bit $u_k$ as

$$L(\hat{u}_k | Y) = \ln \frac{P(\hat{u}_k = 1 | Y)}{P(\hat{u}_k = 0 | Y)} = \ln \frac{\sum_{(s', s) \rightarrow \hat{u}_k = 1} \alpha_{k-1}(s') \gamma_k(s', s) \beta_k(s)}{\sum_{(s', s) \rightarrow \hat{u}_k = 0} \alpha_{k-1}(s') \gamma_k(s', s) \beta_k(s)}. \quad (10)$$

The forward and backward calculations of $a$ and $\beta$ are similar to STTC MAP decoding. Since this is a serially concatenated system without separable systematic information, $Y$ will be regarded as the $L_{P,STTC}$ minus the a priori information of the STTC decoding in the first iteration and will remain the same for the use of all iterations. The a priori information of VLEC decoder ($L_{a,\text{VLEC}}$) in the following iterations will be updated with the extrinsic information from the STTC decoder. The calculation of $y$ can be written as

$$y_k(s', s) = P(Y_k | (s', s)) P(u_k), \quad u_k \in 1, 0, \quad (11)$$

where $u_k$ is the output bit from VLEC encoder associated with transition from previous state $s'$ to current state $s$ at instant $k$ along the trellis. Equation (10) can be further represented as

$$L(\hat{u}_k | Y) = L_{a,\text{VLEC}} + L_{e,\text{VLEC}}, \quad (12)$$

where

$$L_{a,\text{VLEC}} = \ln \frac{P(\hat{u}_k = 1)}{P(\hat{u}_k = 0)},$$

$$L_{e,\text{VLEC}} = \ln \frac{\sum_{(s', s) \rightarrow \hat{u}_k = 1} \alpha_{k-1}(s') P(Y_k | (s', s)) \beta_k(s)}{\sum_{(s', s) \rightarrow \hat{u}_k = 0} \alpha_{k-1}(s') P(Y_k | (s', s)) \beta_k(s)}. \quad (13)$$

Therefore, once the VLEC log-likelihood ratio is calculated, the extrinsic information $L_{e,\text{VLEC}}$ will be extracted and sent to the STTC decoding as the new a priori information.

### 3.2. Iterative information exchange

The principle of iterative decoding is to update the a priori information of each component decoder with the extrinsic information from the other component decoder back and forth. By iterative information exchange, the decoder can
make full use of the coding gain in the coding trellises of the component codes to remove channel noise in a build up way. During the first iteration, the a priori probability to Rec-STTC decoder \( L_{a,STTC} \) is set to be equally distributed over every possible symbol. The log-likelihood output from space time decoder \( L_{p,STTC} \) is separated into two parts: soft information (including the systematic and extrinsic information since systematic information is not separable in space time coding scheme) and a priori information, which, in later iterations, is the extrinsic information from VLEC decoder. The soft symbol information \( L_{x,STTC} \) is extracted and converted to log-likelihood ratio in bit domain. After de-interleaving, it is sent to VLEC decoder as a priori information \( L_{a,VLEC} \). The a posteriori probability output of VLEC decoder \( L_{p,VLEC} \) consists of two parts: a priori information and extrinsic information \( L_{e,VLEC} \). Only extrinsic information is interleaved and converted to the a priori information in symbol domain for Rec-STTC decoder in the next iteration. After the final iteration, Viterbi VLEC decoding is carried out on \( L_{p,VLEC} \) to estimate the source symbol sequence.

The conversion between the bit domain log-likelihood ratio and the symbol domain log-likelihood value is implemented based on the mapping method and the modulation mode. Each symbol \( q \) consists of \( p \) bits \( q \sim \{w_0, w_1, \ldots, w_{p-1}\}, w_i \in \{0, 1\} \). For a group of \( p \) bits \( y_0, y_1, \ldots, y_{p-1} \), we derive the relation between \( L(q) \), \( q = 0, 1, \ldots, 2^p - 1 \) and corresponding \( L(y_i), i = 0, \ldots, p - 1 \) as follows:

\[
L(y_i) = \frac{P(y_i = 1)}{P(y_i = 0)} = \ln \sum_{q \in \{0, 1\}^p} P(q) \frac{\sum_{w_i=0}^{w_i=1} P(q)}{\sum_{w_i=0}^{w_i=1} P(q)}
\]

\[
L(q) = \ln P(q) = \ln \prod_{i=0}^{p-1} P(w_i) = \sum_{i=0}^{p-1} \ln \frac{\sum_{q_{i,1}} P(q)}{\sum_{q_{i,0}} P(q)} = \ln \frac{\sum_{q_{i,1}} P(q)}{\sum_{q_{i,0}} P(q)} = \sum_{i=0}^{p-1} \ln \frac{\sum_{q_{i,1}} P(q)}{\sum_{q_{i,0}} P(q)} = \ln \frac{\sum_{q_{i,1}} P(q)}{\sum_{q_{i,0}} P(q)}
\]

where \( i = 0, \ldots, p - 1 \). In (15), we use a conversion pair between LLR \( L(a) \) and absolute probability \( P(a = 1) \) and \( P(a = 0) \) as follows:

\[
P(a = 1) = \frac{e^{L(a)}}{1 + e^{L(a)}} \quad P(a = 0) = \frac{1}{1 + e^{L(a)}}
\]

4. PERFORMANCE OVER FADING CHANNELS

Throughout this paper, a MIMO system with two transmit antennas and two receive antennas is used to transmit VLEC coded source stream. A symbol stream is first generated and fed to source encoder. Each symbol is drawn from a 5-ary alphabet with probability distribution shown in Table 1. Each input packet has 100 source symbols. We use the VLEC (C1, C2) schemes in Table 1 and the Rec-STTCs (ST1, ST2) with signal constellations in Figure 3. The average transmitted signal power is set to one \( (E_s = 1) \) and the amplitudes of QPSK and 8PSK are both equal to one \( (\sqrt{E_s} = 1) \). The output bit stream from VLEC encoder is padded with “0” if necessary so that its length can be divided by \( p \). Tail symbols are added so that Rec-STTC encoder registers return to zero states. A random interleaver is used between the VLEC encoder and the Rec-STTC encoder. We adopt Rayleigh distributed channel model of both rapid fading case and quasi static fading case.

In this section, we study VLEC C2 concatenated with QPSK modulated Rec-STTC ST1. The overall effective information rate is 1.1856 bit/sec/Hz. Figure 5 shows the SER performance comparison between the joint VLEC and space time decoder and the separable space time and VLEC decoder over quasi static (i.e., block) Rayleigh fading channel and rapid Rayleigh fading channel. The joint source space time decoder achieves more than 2 dB gain over separate decoding in SER in rapid fading channel and about 0.8 dB gain in quasi static fading channel. Especially, at 6 dB in rapid fading channels, after 8th iteration, SER also drops to \( 10^{-3} \) of the SER of separate decoding.

We also observe that the concatenated VLEC and STTC system has a less performance gain in quasi static fading channel than in rapid fading channel, as shown in Figure 5. This is reasonable because the rapid fading channels, which are also called interleaved fading channels, can provide additional diversity gain, compared with the quasi static channel.
5. PERFORMANCE IN PRESENCE OF CHANNEL ESTIMATION ERRORS

In this section, we evaluate the joint source and space time decoding in more realistic scenarios. In Section 3, the decoder assumes in the first place that the channel state information (CSI) is perfectly known at the receiver. However, in real communication systems, regardless of what method is used, there are always errors in the channel estimation. How the joint source and space time decoder performs in presence of channel estimation errors is examined here.

Considering imperfect channel estimation, the actual channel fading matrix \( f \) used to calculate metric in (5) becomes the estimated channel fading matrix \( \hat{f} \). We model each estimated channel fading coefficient \( \hat{f}_{t}^{i} \) as a complex Gaussian random variable, with zero mean and variance of \( \sigma_{i}^{2} \) and is independent on \( f_{t}^{i} \). The correlation coefficient \( \rho \) between \( f_{t}^{i} \) and \( \hat{f}_{t}^{i} \) is given by

\[
\rho = \frac{1}{\sqrt{1 + \sigma_{i}^{2}}}.
\]

Where \( \eta_{t}^{i} \) is the channel estimation error and modeled as a complex Gaussian random variable, with zero mean and variance of \( \sigma_{i}^{2} \) and is independent on \( f_{t}^{i} \). The SER performance in case I and case II over rapid fading channels in Figure 7 shows a similar result. Although channel estimation for rapid fading channels is not practical in real systems, the result provides some theoretic perspectives of the joint VLEC and STTC decoding. Similar decoding gain is observed. After 8 iterations, the joint decoding scheme achieves a performance gain of more than 0.7 dB gain at the level of \( 10^{-3} \) in SER at the level of \( 10^{-3} \) with perfect channel estimation, a performance gain of nearly 4 dB at the level of \( 10^{-2} \) in SER in case I, and a performance gain of more than 5 dB at the level of \( 10^{-1} \) in SER in case II, compared with separate VLEC and STTC decoding.

It can be found that in both quasi static fading channel and rapid fading channel, from \( \rho = 1 \) to \( \rho = 0.95 \), the decoding gain increases. When channel estimation is less accurate, the channel information fed to space time decoder deviates more from correctness and causes more errors. The iterative decoder can still achieve significant improvement over the separate decoding through iterations. Therefore, the joint source space time decoder is robust to channel estimation errors to some extent. The result is also consistent with the decoder’s convergence characteristic. After 6 iterations, the iterative decoding algorithm has
little improvement in case of $\rho = 1$ while iterative gain is still observed in case of $\rho = 0.95$. However, we also did simulations in case of $\rho \leq 0.65$ which means the channel estimation is very poor. We did not find much improvement using the iterative decoding. This is because at this situation, the estimation does not reflect correct information of the actual channel situation and the space time component decoder cannot work effectively to extract the correct information for the iterative utilization.

6. RATE ALLOCATION BETWEEN STTC AND VLEC

The frequency bandwidth resource available to a communication system is always limited, the overall effective data rate that can be transmitted from antennas is hence constrained. The power efficiency is measured by the energy required for transmitting one bit. When communicating at a rate of $R$ with transmit power $E$, the power efficiency is defined as $E/R$. The overall effective data rate depends on both the modulation order of Rec-STTC and the average codeword length of VLEC. On one hand, for a source with given entropy $H$ and a fixed power efficiency, the overall effective information rate is given by $pH/l$. It increases with the modulation order $p$ in Rec-STTC. However, the decoding performance decreases due to a smaller average Euclidean distance between each pair of signal points in the modulation constellation. On the other hand, VLEC with a larger average length $l$ helps to increase error resilience capability due to extra redundancy introduced.

However, this decoding performance is improved at the cost of data rate loss which needs to be compensated later, for example, by the increase of modulation order. As a result, one interesting question is that, given the overall effective information rate and transmit power, whether introducing more redundancy in VLEC or reducing the modulation order of Rec-STTC gives more performance improvement. This question is partially answered in the following simulation.

We study the iterative source space time decoding performance of two different concatenated systems. System I concatenates VLEC C1 with QPSK Rec-STTC ST1. System II concatenates VLEC C2 with 8PSK Rec-STTC code ST2. With the source entropy of 2.14, the average bit length for each source symbol of C1 and C2 equals to 2.46 and 3.61. The bandwidth efficiencies of QPSK and 8PSK equal to 2 bit/s/Hz and 3 bit/s/Hz. System II has a slightly higher overall effective information rate (1.7784 bit/s/Hz) than system I (1.7398 bit/s/Hz). By assigning unit power to each modulated symbol, system II also has a slightly higher power efficiency (1/1.7784 = 0.5607/bit) than system I (1/1.7398 = 0.5748/bit), which means that system II uses less average power to transmit one bit source information.

Figure 8 shows SER performance comparisons between system I and system II over rapid fading channels. The simulation system configuration is the same. System II outperforms system I almost 4 dB at SER of $7 \times 10^{-5}$. The performance comparison between system I and system II in quasi static channels shows a similar result, as in Figure 9.
Therefore, given the roughly same overall information rate and power efficiency, by allocating more redundancy in the source code, the joint source and space time decoding has more iterative decoding gain. However, it also needs to be noted that the better performance of system II is achieved at the cost of higher computation complexity because the number of the states in both VLEC trellis and STTC trellis increases. The complexity of system II is roughly 4 times in STTC decoder and 2 times in VLEC decoder compared with system I. Also, different from rapid fading channel, the quasi static channels provide no additional diversity gain. As a result, system II has a less performance gain over system I in quasi static fading channels.

7. CONCLUSIONS

In this paper, a joint decoder is proposed for serial concatenated source and space time code. VLEC and Rec-STTC are employed with redundancy in both codes. By iterative information exchange, the concatenation system achieves additional decoding gain without bandwidth expansion. Simulation shows that SER of joint decoding scheme is greatly reduced, compared to the separate decoding system in both quasi static and rapid fading channels. The proposed decoder is also shown to be effective with channel estimation errors. Finally, We find that given certain overall effective information rate and transmit power, introducing redundancy in source code can provide more decoding gain than reducing the bandwidth efficiency of STTC, though with increased decoding complexity.

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