PAPER

# New Spatial Diversity with Virtual Constellation Mapping for OFDM Based Wireless LAN

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**SUMMARY** In this paper, to enhance the power efficiency a new simple space-time coding scheme is devised with application to the OFDM based Wireless LAN system. The basic idea is from the receiver's point of view and is referred to as Virtual Constellation Mapping (VCM). We designed a new combination of the channel coding (Turbo Code) along with multiple transmit antennas (Two antennas) to achieve transmit diversity and space division multiplexing transmission. Computer simulation results showed that with the same transmission data rate, our proposed scheme can achieve better bit error rate (BER) compared with the conventional space-time trellis coded OFDM scheme in high Doppler fading channels.

***key words:*** *virtual constellation mapping, space division multiplexing, spectra efficiency, space-time coding, OFDM*

## 1. Introduction

Future wireless communication services should be able to provide high-speed transmission date rate for multimedia applications. Two main objectives in the third generation communication systems are to increase the system capacity and having higher data rates for individual users. Moreover, downlink transmission from the base station to the mobile station is more significant than uplink transmission because the asymmetric nature of the internet traffic such as web browsing and FTP downloads.

One of the traditional methods to increase data rate through bandlimited channel is to use Orthogonal Frequency Division Multiplexing (OFDM) technique [1], [2]. OFDM is a multicarrier transmission technique, which divides available spectrum into many narrowband, low-data-rate carriers, or subcarriers. To obtain high spectral efficiency, frequency responses of the subcarriers are overlapping and orthogonal. Each subcarrier can be modulated using various modulation formats, e.g., BPSK, QPSK and 16-QAM. All subcarriers have to transmit different information data for single user's high-speed transmission application. One of the examples is IEEE 802.11a, which is a Wireless LAN standard based on OFDM modulation. However, its transmission data rate is still limited by assigned available channel bandwidth. To alleviate the effect of interference in a Wireless LAN environment, transmitted power efficiency problems become more significant.

Another effective approach to enhance transmission data rate and power efficiency over wireless channels is to employ coding technique and multiple transmit antennas [3], [4]. In communication systems usually the channel coding techniques, viz., turbo codes and convolutional codes, are employed to protect the information bits from noisy channels. Moreover, to counteract channel fading phenomenon, conventional approach is to use transmit diversity technique, e.g., multiple antennas. The advantage of using transmit diversity technique is that in case the signal received from transmitter antenna #1 is in deep fade, we may be able to get the stronger signal received from transmitter antenna #2, makes communication without a break. In fact, the space-time code [4]–[7] is one of transmit diversity approaches. In [6], [7], the space-time codes are with the block code structure, while in [4] it is based on the convolutional code and is decoded with Viterbi algorithm. Moreover, there are other space-time codes, based on trellis structures, have been suggested in [5], which rely on using iterative decoding fashions. With cost of increasing the encoding and decoding complexity in [5], the BER performances are much better than the simplex ones in [6], [7]. If trellis-based coding techniques are both used simultaneously in the channel encoder and the transmit diversity block, due to such complicated decoding structures, double decoding delays might occur.

The main concern of this paper is to devise a new simple space-time coding scheme, which avoids the drawback just described, and can be applied it to OFDM based Wireless LAN system. The basic idea of this new scheme is to use turbo code associated with the new QPSK mapping for corresponding transmit antennas, referred to as Virtual Constellation Mapping (VCM). To verify the merits of this new scheme, computer simulations will be carried out, and the results are then compared with the OFDM based Wireless LAN system suggested in [8] for high Doppler fading channel environment.

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## 2. New Combing of Channel Encoder and Transmit Diversity

In this section, in order to propose a new simple space-time coding scheme with two transmit antennas, the basic idea of the Space-Time Block Code (STBC) encoder suggested in [6], [7] is first reviewed.

### 2.1 A New Viewpoint for STBC Encoder

The basic idea of the STBC encoder was introduced in [6], [7], and will be described in what follows. As depicted in Fig. 2(a) the STBC encoder is implemented by two transmit antennas with QPSK modulations. Where the QPSK mapping used in this paper is illustrated in Fig. 1. For discussion, we define a $p \times m$ transmission matrix, $\mathbf{G}$; it defines a space-time block code. The entries of the matrix $\mathbf{G}$ are linear combinations of the variables $x_1, x_2, \ldots, x_k$ and their conjugates. The number of symbols in a coded block is $p$ and the number of transmission antenna is $m$. For example, $\mathbf{G_m}$ $(m = 2)$ represents codes, which utilizes two transmit antennas and is defined by [7]

$$\mathbf{G_2} = \begin{pmatrix} x_1 & x_2 \\ -(x_2^*) & x_1^* \end{pmatrix}. \tag{1}$$

In our case, $x_k$, for $k = 1, 2$, is denoted by $Q_{k-1}$, which is one of the symbol values of QPSK. That is, every two successive bits map to a QPSK symbol and then every 2 successive QPSK symbols (e.g. $Q_0$ and $Q_1$) form a valid coded block. The signals transmitted from antenna #1 are $Q_0$ and $-Q_1^*$. On the other hand, the signals simultaneously transmitted from antenna #2 are $Q_1$ and $Q_0^*$, where $Q_0^*$ is the complex conjugate of $Q_0$. For the details of encoding and decoding algorithms, please refer to [6], [7].

Now, we would like to start the analysis of the STBC encoding efficiency from the air combined signal constellation point of view. This analysis is very helpful for proposing our new scheme, which will be discussed in next subsection. When the transmitting QPSK symbols of transmitter antenna #1 and antenna #2 are simultaneously transmitted to the receiver, the signal at receive antenna is a noisy superposition of the two transmitted signals corrupted by channel fading. For illustration, we consider the case with only one receive antenna. The received signal after demodulator is defined by

$$r = C_1 \times h_1 + C_2 \times h_2 + n \tag{2}$$

where $C_1$ and $C_2$ are transmitted QPSK symbols from transmit antenna #1 and #2, respectively. The path gains from transmitter antenna #1 and #2 to receiver antenna are denoted by $h_1$ and $h_2$. The additive white Gaussian noise is denoted by $n$. If there is neither additive noise nor fading factors in the channel, which is an ideal channel condition, $r$ is given by

$$r = C_1 + C_2. \tag{3}$$

We note that because $C_1$ and $C_2$ are QPSK symbols, each of them has four possible values as defined in Fig. 1; therefore, $r$ has 9 possible states as shown in Fig. 2(b). In fact, to represent $r$ we need 4 information bits. However, 4 bits should have a sample space which consists of 16 four-bit states. But, in Fig. 2(b), the STBC encoder has only 9 states in the sample space of the sum of the two QPSK symbols. From the point described above, the STBC decoder needs 2 successive $r$ to make a decision for 4 bits, because a valid STBC coded block contains 2 QPSK symbols. The spectral efficiency of the STBC encoder is

$$\eta_{STBC} = \frac{4\,\text{bits}}{2\,symbol\,periods} = 2\,(\text{bps/Hz}). \tag{4}$$

From (4), we learn that the STBC encoder did not be used to get more spectral efficiency. Based on the observation described above, an alternative approach will be proposed to full utilize the encoding efficiency from the air combined signal constellation point of view.

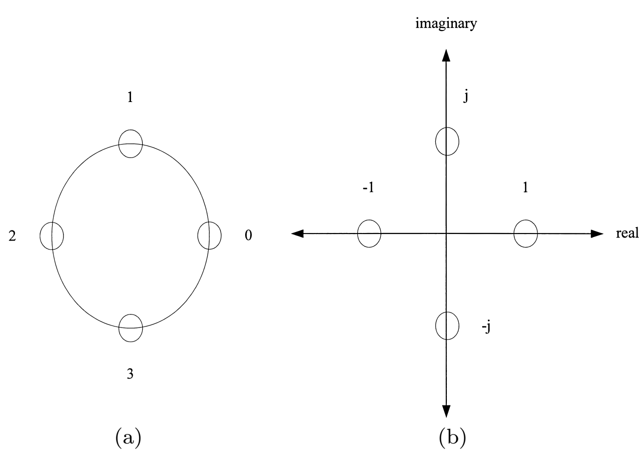


**Fig. 1** (a) The QPSK signal constellation and (b) is its real and imaginary part.

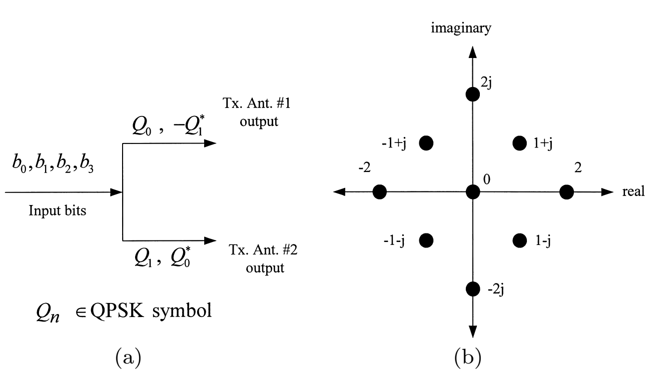


**Fig. 2** (a) The STBC encoder block diagram and (b) is a 9-point signal constellation, that is air combined two transmitted QPSK symbols from Ant. #1 and Ant. #2 in one QPSK symbol period.

### 2.2 Virtual Constellation Mapping

In this subsection, we would like to propose a new simple space-time coding scheme to achieve full utilizing encoding efficiency. In Fig. 3(a), through the Virtual Constellation Mapping (VCM), 3 bits are converted into two QPSK symbols, $C_1$ and $C_2$, in the corresponding transmitter antenna #1 and #2, respectively. Following the similar approach addressed in Fig. 2, we can construct an 8-point signal constellation mapping table. A lookup table which is describing the mapping rule of the VCM is listed in Table 1. That is, if every 3 successive binary bits are fed to the VCM encoder, and a specific set of QPSK symbols for each corresponding antenna output is obtained from Table 1. Where the QPSK symbol be generated for each antenna are equally likely, and each member (state) of the sample space corresponds to one of the 3-bit combinations. It means that with the VCM, we can send 3 bits in one QPSK symbol period, but it is not the case when the STBC encoder is employed. The spectral efficiency of the VCM is

$$\eta_{VCM} = \frac{3\,\text{bits}}{1\,symbol\,periods} = 3\,(\text{bps/Hz}). \tag{5}$$

This means that spectral efficiency is increased from 2 bps/Hz to 3 bps/Hz via the VCM scheme. It is noted here that there is no change of modulation scheme, transmission bandwidth, and transmitted power. Indeed, we have a virtual 8-QASK (Quadrature Amplitude Shift Keying) communication system from the receiver's point of view.

In the receiver, the VCM decoder has to extract 3 soft values for each QPSK symbol period. To do this, we have two steps:

- First, construct a signal space structure which is according to Eq. (2) (ignore $n$), and the combinations of $C_1$ and $C_2$ are specified in Table 1.
- Second, this signal space structure is similar to conventional 8-PSK or 8-QASK; hence we can apply the conventional 8-PSK or 8-QASK demodulator algorithms that can be found in many textbooks to generate three soft values.

It is interesting to compare the performance of (2,1) VCM scheme to (1,1) 8-QASK scheme, where (2,1) denotes two transmit antennas and one receive antenna. From Eq. (2), we observe that the received signal $r$ of the (1,1) 8-QASK scheme, in the form

$$r_{(1,1)8-QASK} = (C_1 + C2) \times h_1 + n. \tag{6}$$

In AWGN channel, there are no fading factors or $h_1 = h_2 = 1$. Therefore, we have the same BER performances. But when in Rayleigh fading channel and it assumes the channels are independent, we can observe that the signal space structure of the (1,1) 8-QASK scheme is fixed. The Euclidean distance between points of the (1,1) 8-QASK signal space are kept the same and all the Euclidean distance only a scale larger or smaller by the fading factor $h_1$. By contrast, the signal space structure of the (2,1) VCM scheme is changed by the fading factors $h_1$ and $h_2$. Hence, all the Euclidean distance does not have the same scale.

Figure 4 illustrates an example of the BER performances of 5 different transmit schemes, QPSK, STBC, 8-point VCM, 8-PSK, 16-state STTC (will discuss later) in AWGN channel. We see that at BER of $10^{-4}$, the 8-point VCM required 9.5 dB Eb/No and QPSK scheme required 8.5 dB Eb/No. But, only the 8-point VCM (also 8-QASK in AWGN) and 8-PSK have spectral efficiency are 3 bps/Hz, the others are 2 bps/Hz. When the channel condition becomes independent Rayleigh fading, the BER performances are illustrated in Fig. 5. If we keep the spectral efficiency be 3 bps/Hz, the gap of Eb/No between the (2,1) VCM scheme and the (1,1) 8-QASK scheme is 1 dB at BER of $10^{-3}$. We also give traditional (1,1) QPSK scheme's curve for a baseline. To be 2 bps/Hz, one channel coding technique, turbo code with coding rate 2/3 is added for the (2,1) VCM scheme and the (1,1) 8-QASK scheme, respectively. At BER of $10^{-3}$, the (2,1) VCM scheme is better than the (1,1) 8-QASK scheme 4.5 dB.

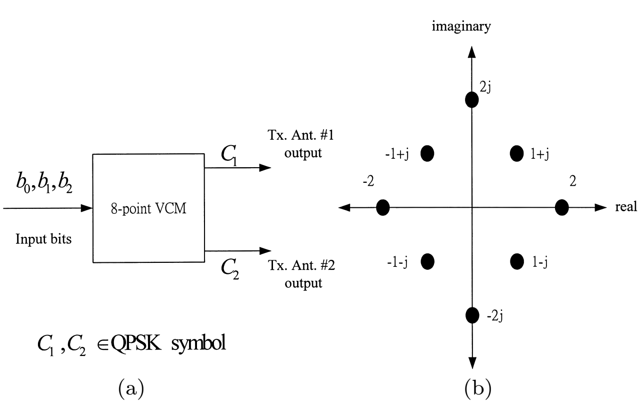


**Fig. 3** (a) The virtual constellation mapping function block and (b) is the 8-point signal constellation.

**Table 1** The input-output lookup table of the 8-point VCM.

| Input Binary Bits | Output QPSK Symbols: QPSK Symbol for Tx. Ant. #1 $C_1$ | Output QPSK Symbols: QPSK Symbol for Tx. Ant. #2 $C_2$ | Air Combined $C_1$ and $C_2$ Real Parts and Imaginary Parts $r$ |
|---|---|---|---|
| 000 | 0 | 0 | 2 |
| 001 | 0 | 1 | 1+j |
| 010 | 1 | 2 | -1+j |
| 011 | 1 | 1 | 2j |
| 100 | 3 | 0 | 1-j |
| 101 | 3 | 3 | -2j |
| 110 | 2 | 2 | -2 |
| 111 | 2 | 3 | -1-j |

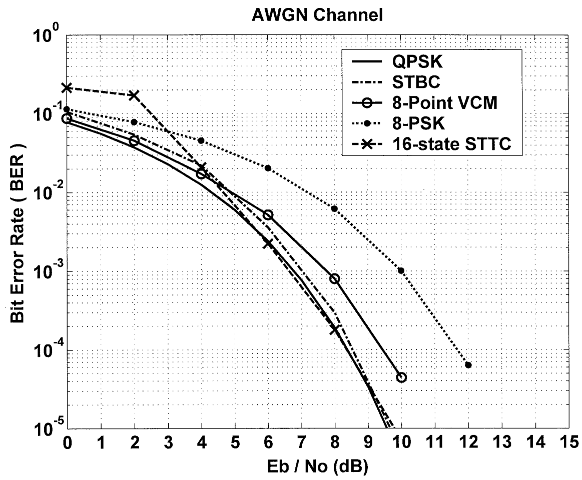


**Fig. 4** The BER performances of the 5 different transmit schemes in AWGN channel. The 8-QASK BER performance is the same as the 8-point VCM case.

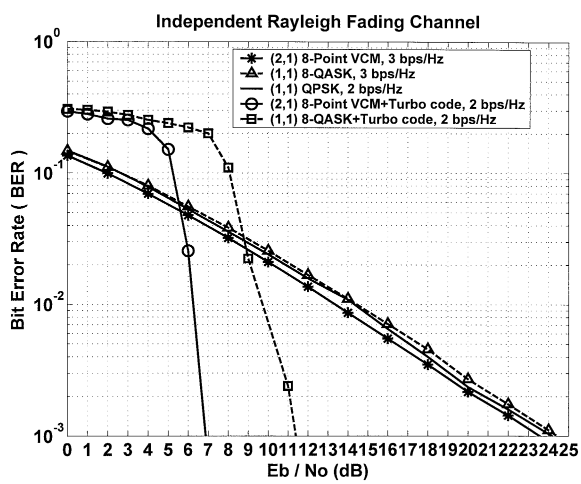


**Fig. 5** The BER performances of the 5 different transmit schemes in Rayleigh fading channel. The turbo coded frame length is 512 bits, and decoding iteration number is 4.

This is because after adding the turbo code, the (2,1) VCM scheme is from pure space coding turn to space-time coding style. While the (1,1) 8-QASK scheme is still time coding only and it can not explore spatial capacity [3]. In what follows, we would like to apply the VCM scheme to the OFDM based Wireless LAN system.

## 3. The OFDM Based Wireless LAN System Models

The block diagram of the OFDM downlink 2 Mbps framework associated with the turbo code using the 8-point VCM scheme, proposed in this paper, is illustrated in Fig. 6(a). For comparison, in Fig. 7, the model of conventional OFDM based Wireless LAN system described in [8], [9] is given. Both wireless communication systems are with the same OFDM modulation structure as shown in Fig. 6(b). Total available bandwidth is 1 MHz, which is divided into 256 subcarrier tones and the information data rate is 2 Mbps. A block contains 512 bits has a frame duration of 256 $\mu$s, is fed to the channel encoder. The channel encoder structure is turbo code of rate 1/3, which is a parallel-concatenated convolutional code (PCCC) with two 8-state constituent encoders and one turbo code internal interleaver. The transfer function of the constituent code for PCCC is [10]

$$G(D) = \left[1, \frac{1+D+D^3}{1+D^2+D^3}\right]. \tag{7}$$

The coded frame outputted from the channel encoder is with length of 1536 bits and is sent to the rate-matching unit with 50% puncture of 1536 bits. That is, we have the net bit rate to be 768 bits. After the 8-point VCM encoder, there are 256 QPSK complex values in one frame duration, 256 $\mu$s. As in [8], the 8-point VCM output has the following code words' form

$$\mathbf{C} = \begin{bmatrix} C_{1,0} & C_{1,1} & \dots & C_{1,255} \\ C_{2,0} & C_{2,1} & \dots & C_{2,255} \end{bmatrix} \tag{8}$$

where $C_{i,k}$ for $i = 1, 2$ and $k = 0, 1, \dots, 255$, belongs to a QPSK constellation, and rows 1 and 2 are the corresponding codewords for transmit antenna #1 and #2, respectively.

The OFDM modulation technology as illustrated in Fig. 6(b) is employed to modulate these codewords and the resulting signal corresponding to both antennas are transmitted simultaneously. For each coded frame, a cyclic extension of 40 $\mu$s is added to avoid any possibly ISI due to the delay spread of the channel. Therefore, a total duration of the OFDM frame is 296 $\mu$s, where data packet length (coded frame) is 250 $\mu$s. Figure 7 is the block diagram of the OFDM downlink 2 Mbps frameworks employs a 16-state space-time trellis code (STTC) [8]. Each codeword in this STTC scheme corresponds to a path of length 256 in the trellis, which can be chosen by a block of 512 bits. The spectral efficiency of these two schemes, Fig. 6 and Fig. 7, is

$$2 \times \frac{256}{296} \times \frac{508}{512} = 1.72\,(\text{bps/Hz}) \tag{9}$$

both schemes have 4 bits for the tail bits. As indicated in [8], without using the spatial diversity, we could not achieve the spectral efficiency of Eq. (9). However, in the robust communication systems usually they will employ channel encoders to operate at low Eb/No. Therefore, in the STTC scheme, an industry standard convolutional code has to be employed for an outer code. That is, the convolutional encoder with a code rate 1/2 and constraint length 7, with generator polynomials (133,171), is used for outer code [2]. To do this, the information data rate is decreased from 2 Mbps to

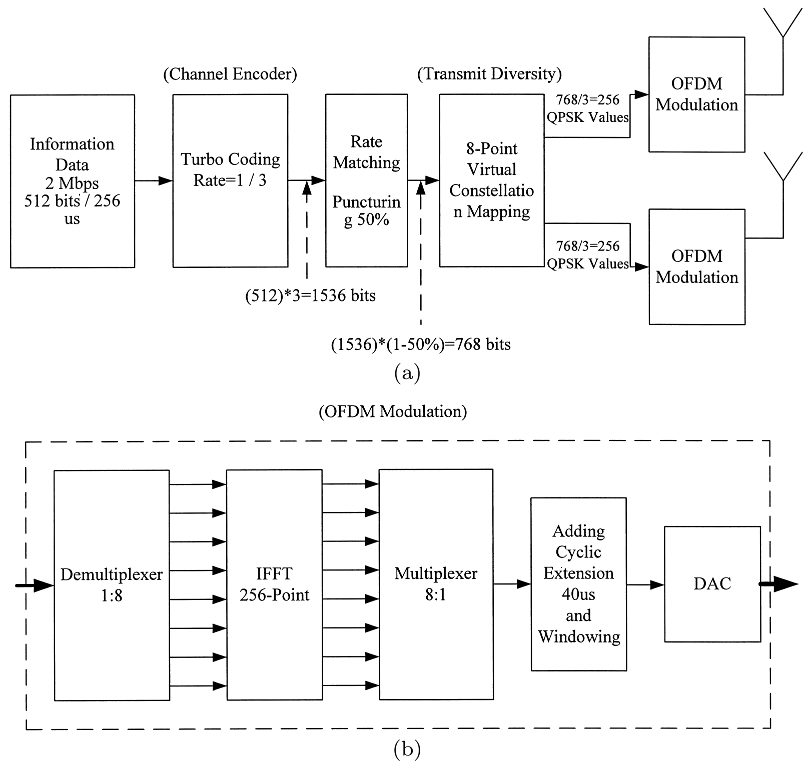


**Fig. 6** (a) The OFDM downlink 2 Mbps framework is formed with the turbo code and the 8-point VCM and (b) is the OFDM modulation structure.

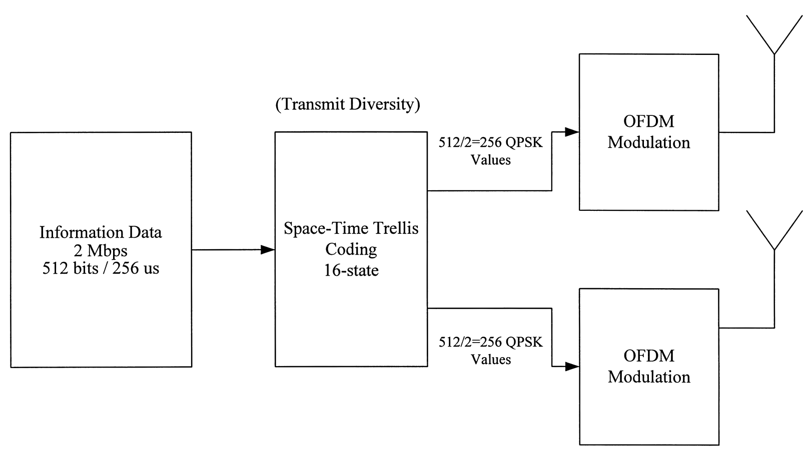


**Fig. 7** The OFDM downlink 2 Mbps framework employs a 16-state space-time trellis code [8].

1 Mbps for keeping the same transmission bandwidth. Accordingly, for the 8-point VCM scheme the puncturing rate is set null.

Next, we would like to introduce the channel models of the OFDM based Wireless LAN system. There are two channel models, the block Rayleigh fading channel and the two-ray Rayleigh fading channel. The block fading means the path gains are constant over one block of size $L$ and are independent from one block to the next block. Here we assume a fading duration is equal to a quarter of an OFDM frame. For the two-ray channel model, each path undergoes independent Rayleigh fading and is assumed to have equal average power. Moreover, the delay spreads of $5\,\mu$s and $45\,\mu$s are considered, where all paths have classical Doppler spectrum and the maximum Doppler frequency is 200 Hz.

The signal at receive antenna is a noisy version of the superposition of the faded versions of the two transmitted signals. The cyclic extension is stripped from each OFDM frame, and these signals are fed to an OFDM demodulator. The output of OFDM demodulator for one receive antenna in frequency domain is given by

$$R_k = H_{1,k} \times C_{1,k} + H_{2,k} \times C_{2,k} + N_k \tag{10}$$

where $H_{i,k}$ are the frequency response of the channel from the $i$-th transmit antenna to receive antenna, at $k$-th subcarrier frequency, and $N_k$ are independent samples of AWGN with variance $N_0/2$. For the details of encoding and decoding algorithms of STTC, we recommend readers the original paper [8].

## 4. Computer Simulation Results

To demonstrate the merits of our method, computer simulations for the two schemes, OFDM with 8-point VCM and OFDM with STTC, are carried out. It is assumed that the perfect channel state information is available to the decoder. While for turbo decoding, the maximum a posteriori (MAP) decoding algorithm with 4 iterations is required. For convenience, simulation parameters are listed in Table 2 and Table 3. First, as convention the case of lower FER at $10^{-2}$ is of interest and is investigated for both schemes in the block Rayleigh fading channel and the two-ray Rayleigh fading channel. From Fig. 8, we learn that at FER of $10^{-2}$, our proposed scheme outperforms the STTC scheme [8] by 1.5 dB. The reason is that the turbo code has a large coding gain in such situation.

Next, the performances of the two-ray Rayleigh fading channels are examined. In these channels, the STTC scheme had added an outer code which is listed in Table 2. The decoding information between the STTC decoding algorithm and the outer decoding algorithm are hard values. From Fig. 9, we observed that for delay spreads being 5 $\mu$s and 45 $\mu$s, our proposed scheme has superior results compared with the STTC scheme (convolutional coded) by 2.5 dB and 3 dB. We also noticed the BER curve of the VCM in 45 $\mu$s delay spread channel has better performance than the VCM in 5 $\mu$s delay spread channel. That is the turbo decoding algorithm with 4 iterations is not enough for taking all the advantage of perfect channel state information in 5 $\mu$s delay spread channel. For the last case, if the STTC scheme (convolutional coded) changes the outer code from convolutional code to turbo code, the results are shown in Fig. 10. The STTC scheme (turbo coded) with 4 turbo decoding iterations is beginning better than the VCM scheme with the same iterations

**Table 2** Simulation parameters for data rate 2 Mbps case.

| Scheme Name | Space-Time Trellis Code with OFDM Modulation | 8-Point VCM with OFDM Modulation |
|---|---|---|
| Information Data Rate | 512 bits/256 $\mu$s =2 Mbps | 512 bits/256 $\mu$s =2 Mbps |
| Data Frame Size | 256 QPSK Vules | 256 QPSK Vules |
| Avaliable Bandwidth | 1 MHz | 1 MHz |
| Subcarrier Tones | 256 | 256 |
| Subcarrier Separation | 1000/256 =3.90625 kHz | 1000/256 =3.90625 kHz |
| Coded Frame Duration | 256 $\mu$s | 256 $\mu$s |
| Cyclic Prefix | 40 $\mu$s | 40 $\mu$s |
| OFDM Frame Duration | 296 $\mu$s | 296 $\mu$s |
| Channel Coding | No | 1/3 Turbo Code, 8 States, Decoding Iteration=4 |
| Rate Matching | No | Puncturing 50% |
| Tx. Diversity | 16-State STTC | 8-Point VCM |
| Bandwidth Efficiency | $2 \times \frac{256}{296} \times \frac{508}{512}$ =1.72 (bps/Hz) | $2 \times \frac{256}{296} \times \frac{508}{512}$ =1.72 (bps/Hz) |
| Channel | Block Rayleigh Fading, $L$=296/4=76 $\mu$s | Block Rayleigh Fading, $L$=296/4=76 $\mu$s |
| FER at $10^{-2}$ | 12.9 dB | 11.4 dB |

**Table 3** Simulation parameters for data rate 1 Mbps case. (Information Data Rate and the other common parameters are the same as the Table 2.)

| Scheme Name | Space-Time Trellis Code with OFDM Modulation | | 8-Point VCM with OFDM Modulation | |
|---|---|---|---|---|
| Channel Coding | 1/2 Convolution Code | | 1/3 Turbo Code, 8 States, Decoding Iteration=4 | |
| Rate Matching | No | | No | |
| Rx. Diversity | 16-State STTC | | 8-Point VCM | |
| Bandwidth Efficiency | $2 \times \frac{256}{296} \times \frac{508}{512} \times \frac{1}{2}$ =0858 (bps/Hz) | | $2 \times \frac{256}{296} \times \frac{508}{512} \times \frac{1}{2}$ =0858 (bps/Hz) | |
| Channel | Two-Ray (fd∗Ts=0.0512) | | Two-Ray (fd∗Ts=0.0512) | |
| | 5 $\mu$s | 45 $\mu$s | 5 $\mu$s | 45 $\mu$s |
| FER at $10^{-2}$ | 6.6 dB | 7.1 dB | 4.1 dB | 3.9 dB |
| Channel Coding | 1/2 Turbo Code, 8 States, Decoding Iteration=4 | | 1/3 Turbo Code, 8 States, Decoding Iteration=10 | |
| FER at $10^{-2}$ | 4 dB | 4.5 dB | 3 dB | 3.5 dB |

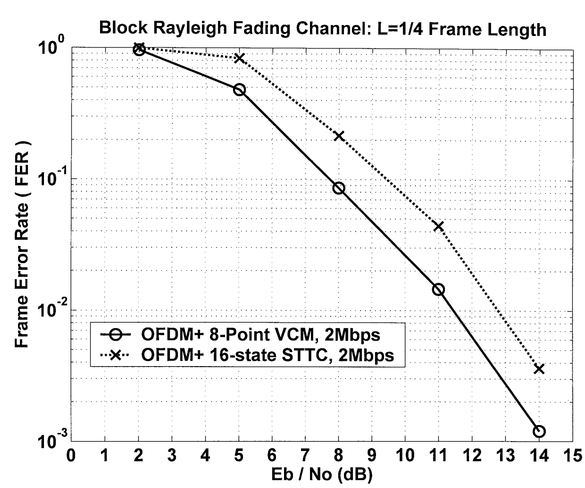


**Fig. 8** FER performance comparison of the 8-point VCM OFDM scheme and the space-time coded OFDM scheme in the block Rayleigh fading channel.

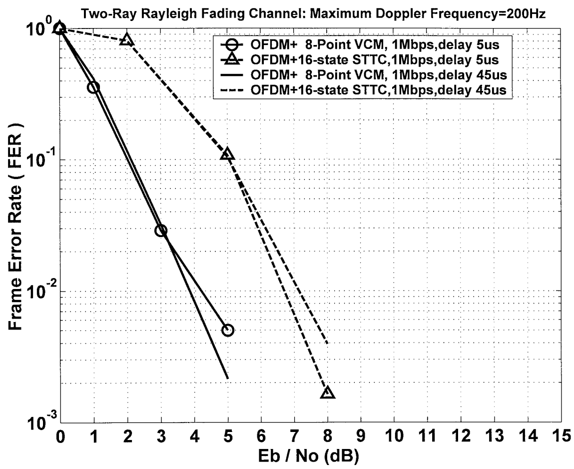


**Fig. 9** FER performance comparison of the 8-point VCM OFDM scheme and the STTC OFDM scheme in the two-ray fading channels.

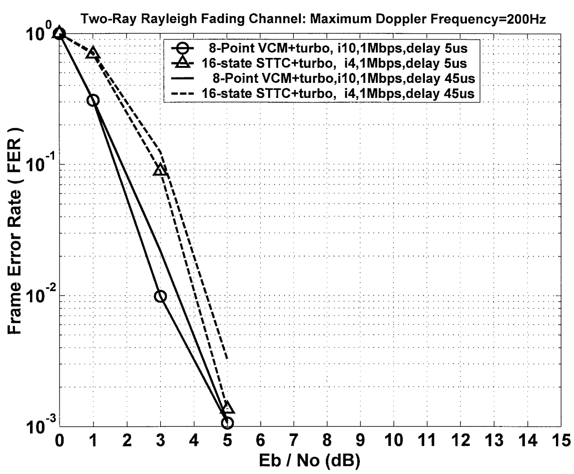


**Fig. 10** FER performance comparison of the STTC concatenated turbo code OFDM scheme and the 8-point VCM OFDM scheme in the two-ray fading channels.

after the FER of $10^{-2}$ in 5 $\mu$s delay spread channel, and the 45 $\mu$s case is still not. However, the trellis states of the STTC scheme with an outer code are larger than the VCM scheme. But, we can adjust the turbo decoding iteration number from 4 to 10 for the VCM scheme. The results are also shown in Fig. 10. The VCM scheme outperforms the STTC scheme (turbo coded) by 1 dB at FER of $10^{-2}$ in two channel cases.

## 5. Conclusions

In this paper, we have devised a new simple space-time coding scheme, and applied it to the OFDM based Wireless LAN system. In this new scheme the turbo code associated with the new QPSK mapping for corresponding transmit antennas, referred to as the Virtual Constellation Mapping (VCM). It was developed to exploit spatial capacity and can achieve high encoding efficiency. From simulation results, we had shown that at the same transmission data rate, our scheme (OFDM with the 8-point VCM) outperformed the conventional space-time trellis coded OFDM scheme by 2.5 dB in high Doppler fading channel. Moreover, this proposed scheme is simple and could be used to achieve full utilizing encoding efficiency and implemented easily.

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