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Performance Evaluation of Improved OFDM-based MTCM in Mobile Communication Systems

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Abstract

In this paper, a performance evaluation of a multiple trellis coded modulation (MTCM) waveform is proposed for mobile channel environments. In order to reduce received SNR in BER 1.0E-6 conditions, we proposed a 32 trellis coded modulation (TCM). We also applied orthogonal frequency division multiplexing (OFDM) technologies such as timing recovery, carrier recovery, and equalizer, in order to reduce robust channel impairments caused by non-line-of-sight (NLOS) environments where a signal is not received from another system. Simulation results show that coding gain of a 32 trellis coded OFDM waveform has about 6 dB and 2 dB, compared to single-carrier 16-QAM waveform and OFDM (16-QAM) waveform in mobile communication systems, respectively.

Keywords: MTCM, OFDM waveform, symbol timing, frequency offset, equalization

1 Introduction

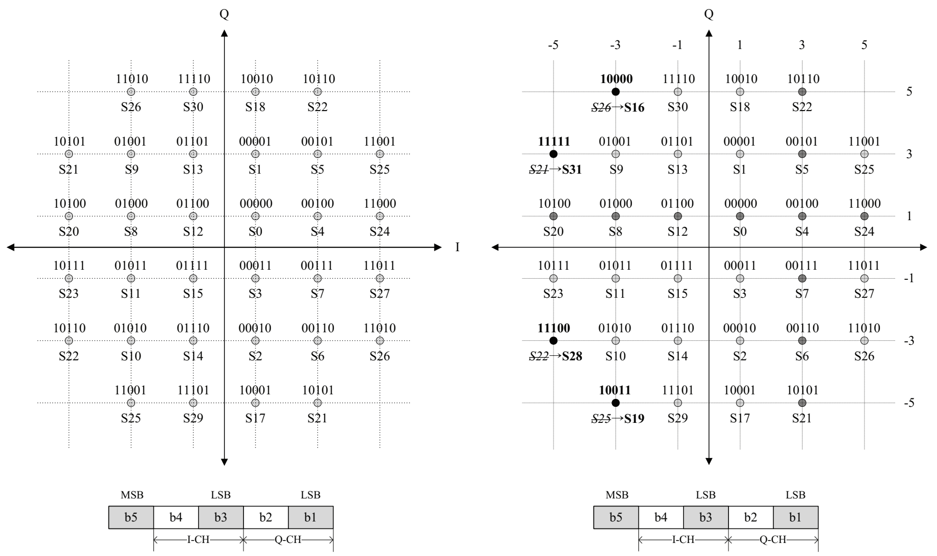
Due to the fast development of information technology, the high-capacity radio must be able to provide a transmission speed of several MHz to several Mbps and a bit error rate (BER) of less than 1.0E-6 data quality [1]. To satisfy the demanding requirements of high-capacity radio, we have proposed a 32 trellis coded OFDM waveform. Some of the important features of this waveform adopt TCM to improve BER performance without increasing occupied bandwidth or transmit power. This requires a modified pragmatic method to overcome the limitation of the conventional pragmatic method (2^N, $N =$ even only), which could not design 2^N TCM, and application of OFDM, that is resistant to frequency selective fading, which occurs, not only in the LOS mobile channel, but also as a result of multipath in a NLOS environment [2][3].

2 Proposed Mapping and Decoding Rules

The frame format structure used in this study is designed such that the preamble symbols and the data symbols are transmitted alternately. In the preamble interval, the uncoded known symbol is transferred and the receiver performs integer frequency offset and channel estimation by using this. As for the modulation technique, we applied 32 TCM, which combines error-correcting code with a modulation technique. We designed a cyclic prefix to compensate as much as possible for the delay spread that derives from the multipath.

As for the method of mapping the configuration point of 32 TCM, the bit string of the configuration point was first defined as shown in Figure 1(a), following the mapping rule of Kokuryo and Tsukamoto [2]. Next, for the most significant bit, uncoded bits of 1 are mapped outside and those of 0 are mapped inside, using 16 constellations as the boundary. Third, each of 2 bits generated from the convolutional encoder (1/2) are allocated separately, to b3 and b1. Such allocation creates overlaps in four configuration points (S26, S21, S22, and S25). As shown in Figure 1(a), the problem can be resolved when these four configuration points are transferred after being changed to S16, S31, S28, and S19 and recovered in the receptor through a decoding algorithm.

Figure 1(b) shows the process of distinguishing bits in a 32 TCM decoder. The scheme for extracting b3 and b1 from the bit string is identical to the pragmatic scheme of Kokuryo and Tsukamoto [2]. Next, b4 and b5_I are distinguished by using the coded bit of the I-channel, b3; b2 and b5_Q are distinguished by using the coded bit of the Q-channel, b1. Finally, there exists overlapping bit string when b5_I and b5_Q are extracted through OR computation for b5 along the bit string; the bit string on the receptor side is extracted as shown in Figure 1(b). For these four overlapping configuration points, transferring bit string can be recovered by applying the rule described in reference [2]. Final information can be recovered by taking the original



(a) Bit definition by mapping rules. (b) Bit distinction by decoding rules.

Figure 1: Constellations of proposed 32 trellis coded modulation.

information of b5, b4, and b2 among the finally extracted b5, b4, b3, b2, and b1 and combining the Viterbi decoder output of b3.

3 Fractional Frequency Offset

In OFDM, synchronization is very important because, unlike single carrier waves, OFDM recovers data by OFDM symbol(FFT+CP) in the receiver and is very sensitive to the frequency offset. Therefore, we explained the OFDM synchronization blocks that connect with 32 TCM.

Unlike single carrier systems, OFDM recovers data through the block unit in the receptor. Hence, the performance of the synchronizer is very important, and it is particularly sensitive to frequency offset. As for the timing recovery and compensation of the fractional frequency offset, this study applies an algorithm by which to simultaneously obtain fractional frequency synchronization and timing synchronization, by using the cyclic prefix; this is in line with the technique of van de Beek [3]. In general, integer frequency offset means that the location of the symbol moves when demodulating the received signal. Fractional frequency offset distorts the amplitude and phase of the data symbol by causing inter-carrier interference (ICI).

When time delay (τ) and carrier frequency offset (ε) are given in an additive white Gaussian noise channel environment, the log-likelihood function $\Lambda(\tau, \varepsilon)$

on τ and ε is the logarithm of the probability density function $f(r|\tau,\varepsilon)$ of the $2N$ + L observed samples of the received signal $r(k)$. The log-likelihood function that uses the correlation properties of $r(k)$ can be written as follows [3].

$$\Lambda(\tau,\varepsilon) = \log f(r \mid \tau,\varepsilon) = \log\left(\prod_{k\in\Gamma} \frac{f(r(k)),r(k+N)}{f(r(k))f(r(k+N))} \prod_{k\notin\Gamma\cup\Gamma'} f(r(k))\right) \tag{1}$$

Here, $f(\cdot)$ indicates the probability density function of a variable in argument. Since product $\prod_{k} f(r(k))$ is orthogonal to τ and ε and the maximum likelihood (ML) estimation of τ and ε are arguments that maximize $\Lambda(\tau,\varepsilon)$ in equation (1), we can omit this element. Assuming that $r(k)$ is jointly Gaussian, the maximization condition for the conditional probability $\Lambda(\tau,\varepsilon)$ in equation (1) is as follows.

$$\max_{(\tau,\varepsilon)} \Lambda(\tau,\varepsilon) {=} \max_{\tau} \Lambda(\tau,\hat{\varepsilon}_{ML}(\tau)) \tag{2}$$

Here, $\angle$ is the argument of a complex number and $\angle\gamma(\tau)$ and $\Phi(\tau)$ are as described in van de Beek and Sandell [3]. Hence, the joint ML estimation of τ and ε can be written as follows.

$$\hat{\tau}_{ML} = \arg\max_{\tau}\{|\gamma(\tau)| - \rho\Phi(\tau)\}\ , \qquad \hat{\varepsilon}_{ML} = -\frac{1}{2\pi}\angle\gamma(\hat{\tau}_{ML}) \tag{3}$$

This study applies a scheme by which to eliminate offset in the pre-FFT of the receptor by considering the hardware complexity and the convenience of implementation. Assuming that $rx_k[n]$ is the nth time-domain sample of the kth received OFDM symbol and $tx_k^*[n]$ is the time-domain sample through the nth conjugation computation of the kth known preamble OFDM symbol, signal $y[n]$ generated by the product of the received signal and baseline signal can be written as equation (4).

$$y[n] = rx_k[n]tx_k^*[n], \quad 0 \le n \le N-1 \tag{4}$$

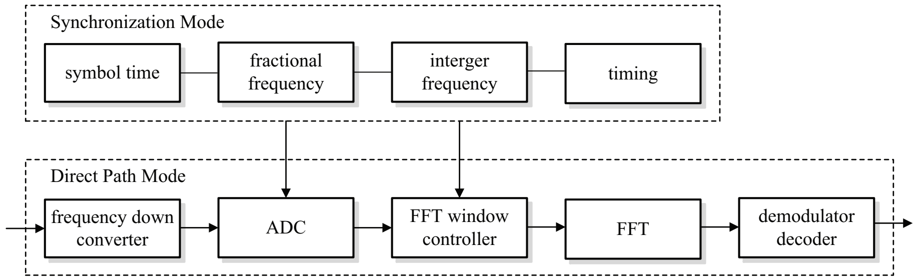


Figure 2: Integer frequency offset estimation.

As shown in equation (5), the $y[n]$ frequency offset is estimated by detecting the point at which the size of the frequency domain signal $y[n]$ is maximized [4][5].

$$\hat{\varepsilon}_k = \max_k |\mathrm{Y}[k]|\,, \quad 0 \le k \le N-1 \tag{5}$$

4 Integer Frequency Offset

Figure 2 shows the implementation process while using equations (4) and (5). To compensate for the frequency selective fading that occurs in mobile channel environments, as well as to facilitate implementation, this study recovers the received signal in the kth subcarrier of the lth symbol by applying a zero forcing equalizer, and the received data by applying the least square channel estimation scheme.

Moreover, we apply an algorithm that effectively reduces the impact of the residual frequency offset by using equalizer output and decoder output [6]. The residual frequency offset distorts size by causing interruption among subcarriers, and it rotates the symbol phase. Here, the rotation of phase differs for every symbol. Hence, we can estimate the residual frequency offset based on this difference in phase [7][8][9]. The phases of the first and the second symbols can be written as equations (6).

$$\hat{\tau}_l = \tan^{-1}\frac{\sum_{k=0}^{N-1} Im[rx_{l,k}\hat{r}x^*_{l,k}]}{\sum_{k=0}^{N-1} Re[rx_{l,k}\hat{r}x^*_{l,k}]}\,, \qquad \hat{\tau}_{l+1} = \tan^{-1}\frac{\sum_{k=0}^{N-1} Im[rx_{l+1,k}\hat{r}x^*_{l+1,k}]}{\sum_{k=0}^{N-1} Re[rx_{l+1,k}\hat{r}x^*_{l+1,k}]} \tag{6}$$

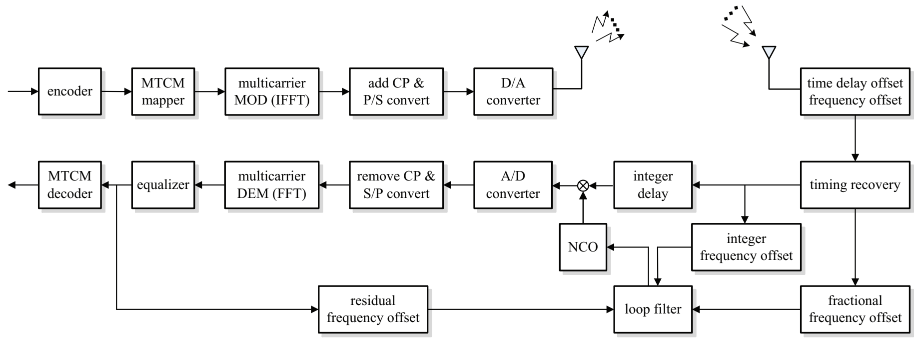


Figure 3: Block diagram of proposed OFDM-based MTCM system in the SUL-2 wireless channel.

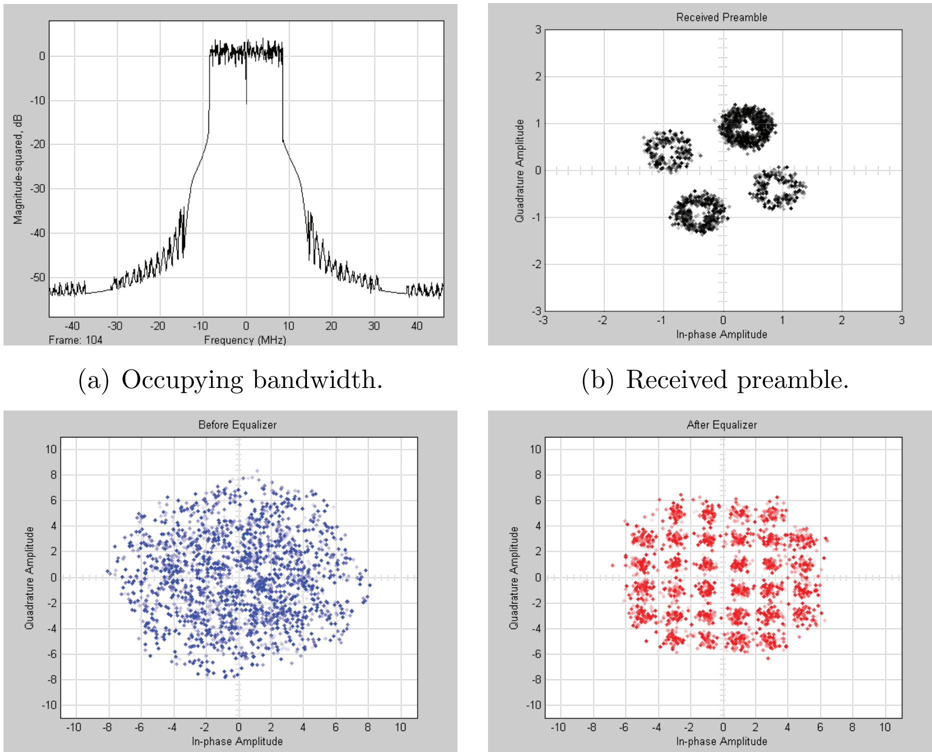
The residual frequency offset based on them can be written as equation (7).

$$\hat{\varepsilon}_l = \frac{(\hat{\tau}_{l+1} - \hat{\tau}_l)}{2\pi T_s D} \tag{7}$$

5 Test Results and Discussion

Figure 3 is a block diagram for an OFDM-based MTCM system. To analyze the performance of the OFDM-based 32 TCM waveform, we compared its performance with that of 16QAM OFDM waveform, in terms of BER, within the context of the Stanford University Interim-2 (SUI-2) wireless channel model.

Figures 4 and 5 show the change in the received signal of the function block of the waveform and the BER performance of the suggested OFDM-based TCM waveform, respectively. As shown in Figure 5, use of the OFDM-based 32 TCM greatly improved receiving performance by improving the required signalnoise ratio by approximately 6dB compared to the single carrier (16QAM) waveform and by approximately 2dB compared to the OFDM (16QAM) waveform, when using BER 1.0E-5 as the standard.



(a) Occupying bandwidth.

(b) Received preamble.

(c) Before equalization.

(d) After equalization.

Figure 4: The received signal change of the waveform.

6 Conclusions

As shown in Figure 5, any inter-symbol interference (ISI) that occurs in the mobile channel environment can be efficiently eliminated by applying OFDM and TCM can be simultaneously applied to gain additional coding gain (about 2 dB and 6 dB). Therefore, the proposed waveform should be able to maintain its coding gain over an OFDM (16-QAM) and the single carrier 16-QAM, as predicted by the simulation results. As a result of this paper, it can be used as a mass transfer waveform for mobile transmission devices in mobile communication systems or next generation mobile networks.

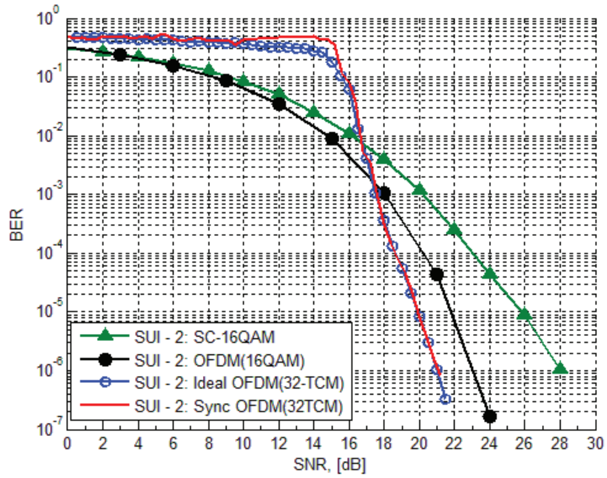


Figure 5: BER performance of OFDM-based TCM waveform.

References

[1] M. Harada, T. Yamazato, M. Katayama and A. Ogawa, OFDM Systems with Multiple Trellis-coded Modulation, *11th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications,* 2000. https://doi.org/10.1109/pimrc.2000.881535

[2] Y. Kokuryo and N. Tsukamoto, Pragmatic Trellis Coding Applied to Rectangular QAM, *IEEE Consumer Electronics,* **51** (2005), 365-370. https://doi.org/10.1109/tce.2005.1467973

[3] J.J. van de Beek, M. Sandell and P.O. Borjesson, ML Estimation of Time and Frequency Offset in OFDM systems, *IEEE Trans. On Sig. Proc.,* **45** (1997), 1800-1805. https://doi.org/10.1109/78.599949

[4] H. Kobayashi, K. Mori and T. Nagaosa, Proposal of Symbol Timing and Carrier Frequency Synchronization Methods for Burst Mode OFDM Signal, *IEICE Trans. Commun.,* **E86-B** (2003), 238-246.

[5] A. Hashib Siddique, A.K.M. Arifuzzman and M. Tarique, Performance Study of IEEE 802.16d under Stanford University Interim (SUI) Channel, *International Journal of Computer Networks & Communications,* **5** (2013), 137-152. https://doi.org/10.5121/ijcnc.2013.5211

[6] D. Divsalar and M.K. Simon, Multiple Trellis-coded Modulation (MTCM), *IEEE Trans. Commun.,* **36** (1989), 410-419. https://doi.org/10.1109/26.2765

[7] A.J. Viterbi, J.K. Wolf, E. Zehavi, R. Padovani, A Pragmatic Approach to Trellis-Coded Modulation, *IEEE Communications Magazine,* **27** (1989), 11-19. https://doi.org/10.1109/35.31452

[8] G. Ungerboeck, Trellis-Coded Modulation with Redundant Signal Sets Part I: Introduction, *IEEE Communications Magazine,* **25** (1987), 5-11. https://doi.org/10.1109/mcom.1987.1093542

[9] G. Ungerboeck, Trellis-Coded Modulation with Redundant Signal Sets Part II: State of the Art, *IEEE Communications Magazine,* **25** (1987), 12-21. https://doi.org/10.1109/mcom.1987.1093541

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