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Filter bank multi-carrier based offset ternary phase shift keying(FBMC/OTPSK)

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Abstract. Filter bank multi-carrier (FBMC) is a popular researched technique for wireless communications that offers several advantages over traditional orthogonal frequency-division multiplexing (OFDM) systems. In this paper, we propose a FBMC system using offset Triangle phase shift keying (TPSK) modulation (FBMC/OTPSK), analyze its bit error rate (BER) performance via additive white Gaussian noise (AWGN) channel, and compare it to that of conventional FBMC using offset quadrature amplitude modulation (FBMC/OQAM) system. Simulation results show that the proposed FBMC/OTPSK system considerably improves BER performance over FBMC/OQAM system. Additionally, we explore the impact of using ternary convolutional coding (TCC) with TPSK and binary convolutional coding (BCC) with QAM. The presented TPSK modulation encoded by TCC offers better error rate performance and minimum amplitude fluctuation compared to QAM encoded by BCC; therefore, TCC-coded OTPSK is proposed to be used with FBMC instead of BCC-coded OQAM to benefit from its lower error rates without bandwidth expansion, as well increase information carried by symbol, hence increases throughput.

1. Introduction

In order to meet the rising demand for wireless communication and future wireless networks, several techniques are investigated. This rising need is a result of the greater use of mobile devices and sensors in the real world [1]. One of these techniques is Multi-Carrier Modulation (MCM) which involves dividing the data stream into many concurrent sub-streams and transmitting each sub-stream on a distinct frequency or sub-carrier [2, 3]. Orthogonal frequency-division multiplexing (OFDM) is the most popular MCM technique used in wireless and cellular communications. OFDM is preferable in point-to-point communication as well as unmanned aerial vehicle UAV wireless communications [4] because it can be implemented with the least amount of complexity [5]. However, it has a number of challenges, such as low spectral efficiency and significant out-of-band emissions [6]. Several modulation strategies are now being researched in order to address these issues, with Filter bank multicarrier (FBMC) being one of them.

FBMC achieves higher bandwidth efficiency than OFDM by a carefully designed prototype filter, FBMC delivers an improved spectral shaping of sub-carriers and due to excellent frequency localization it has less out-of-band emission and less gain side lobes than OFDM [7].For the purpose of increasing power effectiveness and error rate characteristics of FBMC, here ternary phase shift keying (TPSK) is used instead of quadrature amplitude modulation (QAM) in FBMC. However, TPSK is not appropriate for sending binary information signals, hence it has not received much attention up till now. Nevertheless, it has theoretically outstanding

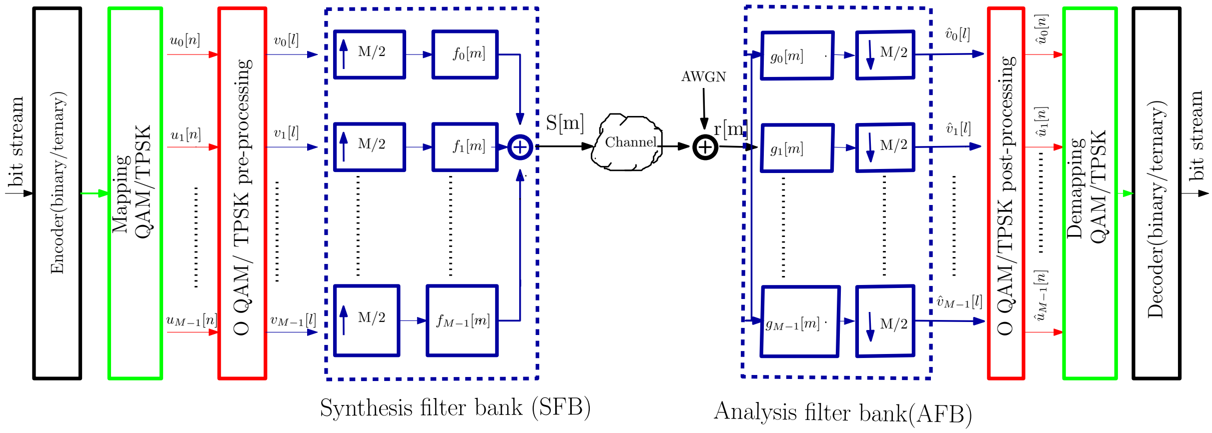

Figure 1 FBMC based OTPSK/OQAM.

features for mobile communication systems, namely, it has a lower error rate performance and the least amount of amplitude variation among all PSK schemes [8]. Therefore the latter feature is highly tempting for mobile terminals where non-linear amplifiers are required [9].

The TPSK technique is proposed to be implemented in real-world systems using a new class of convolutional codes[10]. The TPSK method with the new convolutional code is appropriate for sending binary signals and it enhances the characteristics of the error rate without expanding the bandwidth[11, 12]. The utilization of ternary systems is thought to be a promising technology for the future and can reduce the amount of hardware resources needed. As one trit equals $\log 2(3) = 1.58$ bits, Compared to a binary symbol, a ternary symbol can hold more data, and TPSK modulation uses less bandwidth than QPSK [13]. Moreover, comparing BER for TPSK and QPSK at same SNR, its proved that TPSK has lower BER than QPSK [8]. The greatest free distance for ternary convolutional codes (TTC) are provided with a rate of 1/2. The performance of TCC with TPSK is compared to QAM with BCC in FBMC.

In this paper, we investigate exploiting a new mapping method (TPSK) with FBMC. Offset TPSK (OTPSK) is introduced and combined with FBMC (FBMC/OTPSK) to improve its power efficiency. This paper is arranged in the following sections; section I gives the introduction and highlights the potential of the FBMC technique and explores the outperformance of TPSK over QAM. Section II illustrates the proposed system model. Section III discusses the simulation results. In section IV, The conclusions are made.

2. System Model

The theoretical and technical aspects of FBMC have been comprehensively introduced in many studies e.g. [7, 6]. FBMC system's general block diagram is depicted in figure 1 along with its overall flow. The main processing units in this direct formulation are the encoder (binary/ternary), mapping (QAM/TPSK), pre-processing (OQAM/OTPSK), synthesis filter bank (SFB), analysis filter bank (AFB), post-processing (OQAM/OTPSK), demapping (QAM/TPSK), and decoder (binary/ternary). In this paper, we assume the signal S$[m]$ in the transmultiplexer(TMUX) system propagates over an ideal channel. The convolutional codes that are non-systematic and non-recursive are taken into consideration. Three parameters (n, k, and q) are used to describe convolutional codes, where n refers to the length of the encoder's input stream and k refers to the output stream, while q is the size of the encoder memory. $R = k/n$ represents the coding rate. For TCC, firstly a binary stream of bits is converted to a ternary stream of trits by binary to ternary conversion, where each 3 bits are converted to 2

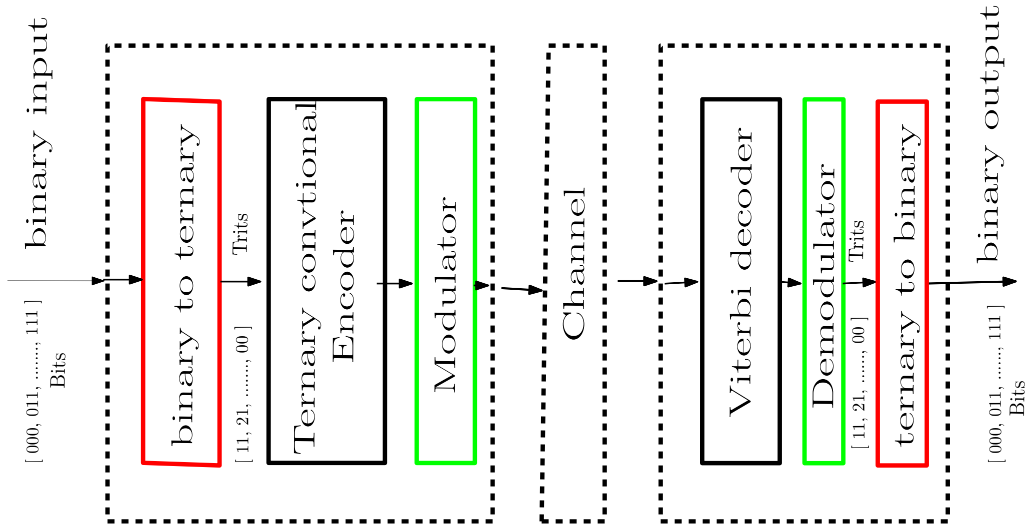

Figure 2 Binary to ternary adaptation

trits shown in figure 2 [13]. For all operations (encoding and decoding) done in the finite field of three elements GF(3), a code rate of 1/2 is used. A generator matrix D(s) of size $k \times n$ can represent a (n, k,q) TCC. D(s) has n generator polynomials, each of degree q, called $d_i(s)$ can be written as

$$d_i(s) = a_{i,q}(s)^q + a_{i,q-1}(s)^{q-1} + a_{i,q-2}(s)^{q-2} + ... + a_{i,0}, \tag{1}$$

where $a_{i,c} \in \{0, 1, 2\}$, $c \in \{0 : q\}$. for example, in our work $D(s) = [d_1(s) \quad d_2(s)]$, $d_1(s) = s^3 + s + 2$ *and* $d_2(s) = 2s^3 + s^2 + 1$ [11]. The majority of the complexity is in a convolutional decoder. The Viterbi method is a popular maximum-likelihood decoder with a low degree of implementation complexity. An equivalent value of q, k, and n results in a ternary decoder that is more complicated than a binary decoder.

signal constellation diagrams and decision boundaries for TPSK and 4-QAM are illustrated in figure 3. Gray code in employed instead of binary code for QAM mapping to minimize the bit errors, as just one bit varies between neighbouring signal constellation points. The elements {0, 1, 2} of GF(3) are mapped to TPSK symbols as, $\{\ E,\ -E/2 + i\sqrt{3}E/2,\ -E/2 - i\sqrt{3}E/2\}$ respectively. In order to maintain the same bit energy for a comparison reason, 4-QAM are mapped to $\{\pm\sqrt{log_2 3 \times E},\ \pm i\sqrt{log_2 3 \times E}\}$ which makes TPSK constellation points have a larger minimum distance over 4-QAM by a factor of $\sqrt{3log_2 3}/2$, which makes the TPSK error rate better than 4-QAM.

Instead of QAM / TPSK symbols, the TMUX system is excited by OQAM / OTPSK symbols in the transmitter side. figure 4 represents the pre-processing that converts the QAM to OQAM symbol where each complex symbol $u_k[n]$, $k = 0, 1, ..., M-1$ is splitted into two successive symbols $v_k[l]$, (real and imaginary fields) which are ordered according to sub-carrier index k (even / odd) (staggering operation). Therefore the sub-carrier index is the key factor in how these new symbols are ordered. As a result, the sample rate of $v_k[l]$ is doubled due to the staggering process. In the receiver side, the reverse process is done by merging the real and imaginary fields of the successive complex symbols in the signal $\hat{v}_k[l]$ according to the sub-carrier index k and discarding the other field in each symbol as depicted in figure 4, therefore, the sample rate of $\hat{u}_k[n]$ is half of the sample rate of $\hat{v}_k[l]$.

Signal processing systems called filter banks are used to split up a signal into several sub-carrier. They are frequently employed in telecommunications, picture and audio processing, and other applications. The two primary components of filter banks are synthesis filter banks in the

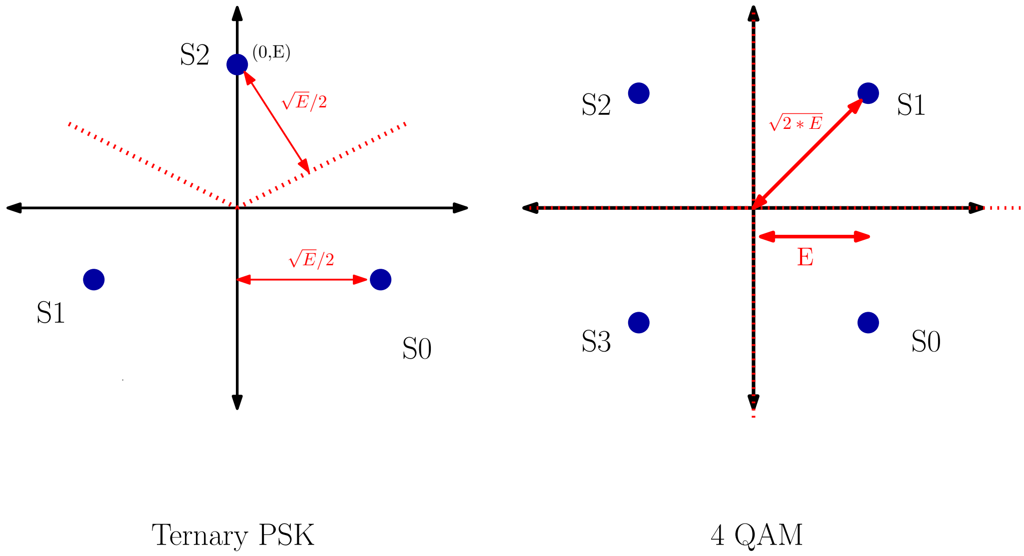

Figure 3 Constellation diagrams for TPSK and 4-QAM

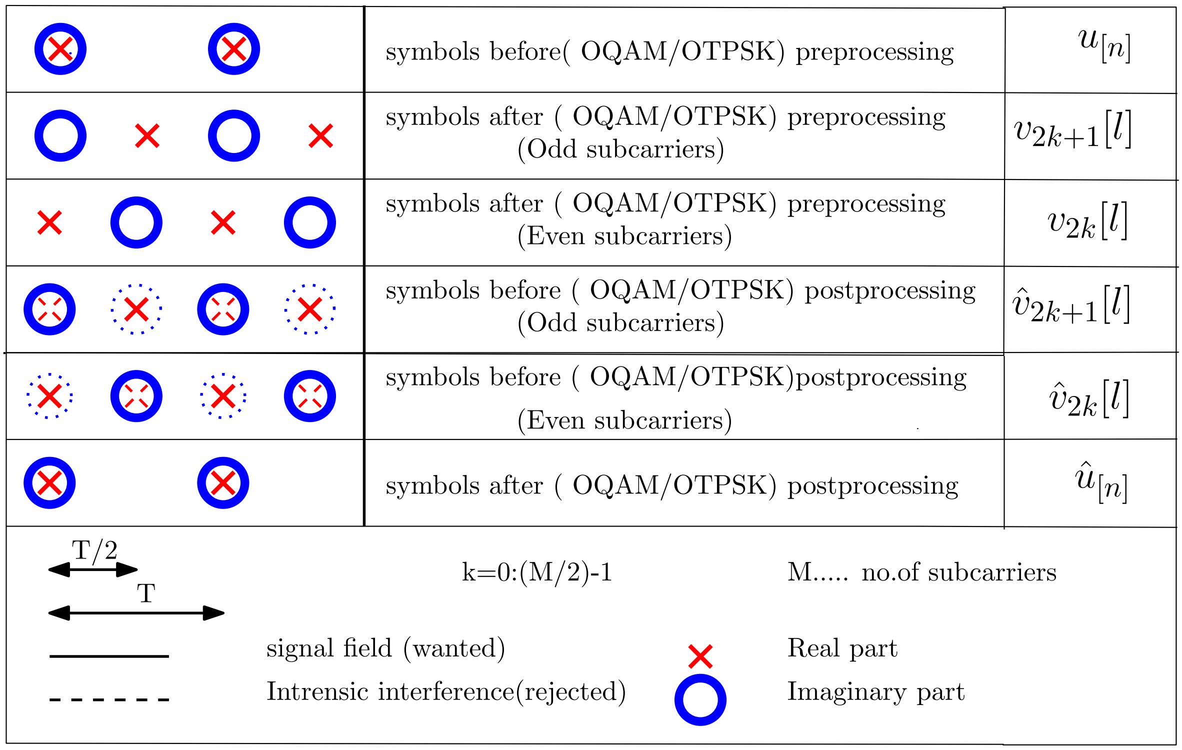

Figure 4 Conversion process between QAM/TPSK and OQAM/OTPSK in Tx and Rx

transmitter and analysis filter banks in receiver.

A signal is divided into many sub-bands by analysis filter banks by sending it through a collection of band-pass filters. Each band-pass filter's output is referred to as sub-carrier. Where $v_k[l]$ is the input signal, $f_k[m]$is the impulse response of the k^{th} band-pass filter, $s[m]$ is the multiplexed output of the filters, and M is the number of sub-carriers, the implementation of AFB is produced with the use of M synthesis filters and M up-samplers, as seen in figure 1. The signals $v_k[l]$ are up-sampled by a factor of $M/2$ and then filtered using $f_k[m]$, the SFB output signal $s[m]$ is formed by multiplexing all sub-signals from M synthesis filters.

The received signal $r[m]$ arises from the propagation of the signal S[m] over an ideal channel and is corrupted by AWGN then it is demultiplexed by synthesis filters $g_k[m]$ and then down-sampled by $M/2$. Using exponential modulation, a low pass filter has linear phase in real domain is used to generate complex modulated filter banks with all sub-channel filters $h[m]$ [7]. The modulation function causes the sub-carrier filters $f_k[m]$ that are produced to be complex-valued.The formula for the kth synthesis filter is [7]

$$f_k[m] = h[m]\ exp\left(\frac{i2\pi k}{m}\left(m - \frac{(L_h - 1)}{2}\right)\right), \tag{2}$$

where $m = 0, 1, \ldots, L_h$ and L_h is the filter's length. The filter $g_k[m]$ is reconstructed from synthesis filter by two simple operations, time reversal is the first one then taking its complex-conjugated version of first operation as,

$$g_k[m] = f_m^*(L_h - 1 - m) \tag{3a}$$
$$= h(L_h - 1 - m)exp\big(2\pi k/m(L_h(1 - m - (L_h - 1)/2))\big) \tag{3b}$$
$$= h[m]exp(i2/\pi km(m - (L_h - 1)/2)). \tag{3c}$$

According to one interpretation of the equations above, causal sub-channel filters are constructed from a linear phase filter $h_[m]$ which leads to that the sub-channel filters all posses linear phases.

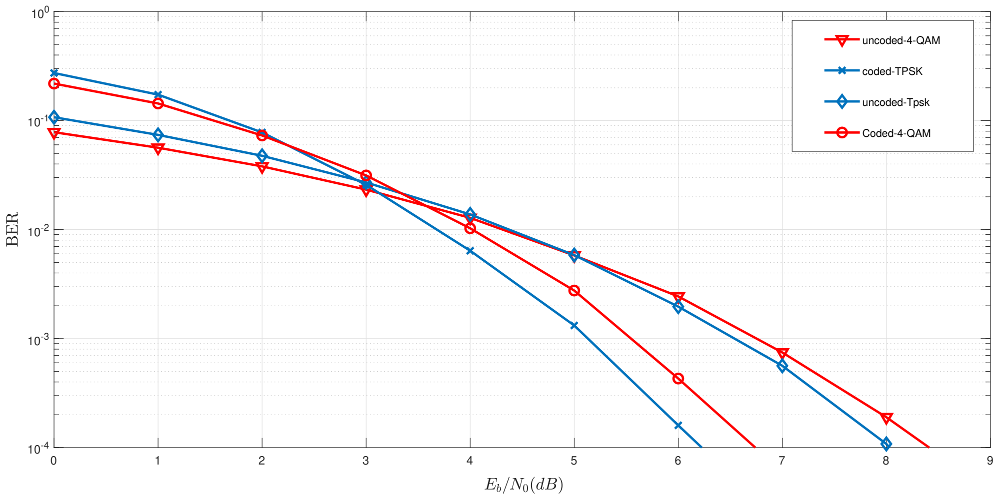

Figure 5 Bit error rate of TPSK and 4-QAM over AWGN channel

3. Simulation and results

In this section, the probability of the bit error rate for TPSK and 4-QAM is measured over AWGN channel. With 10^5 bits for each value of E_b/No Simulation is performed, where E_b is the average energy per bit and N_o is the noise power spectral density. For a fair comparison, the values of E_b for TPSK and 4-QAM must be the same. This is done by normalizing the energy of constellation points of TPSK and 4-QAM. The BER of TPSK and 4-QAM with convolutional codes and without it is shown in figure 5. The BER performance for uncoded TPSK is better

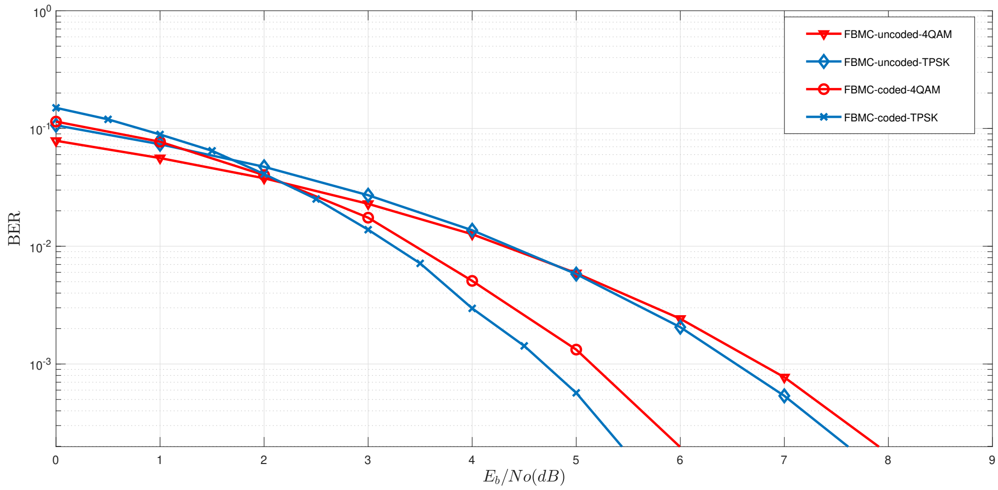

Figure 6 Bit error rate of FBMC/OTPSK and FBMC/OQAM over AWGN channel

than uncoded 4-QAM by 0.24 dB at BER= 10^{-3} and BER performance for coded TPSK is better than coded 4-QAM by 0.44 dB at BER=10^{-3}.

In figure 6, the BER of TPSK and 4-QAM with convolutional codes and without it in the FBMC system is illustrated. The BER performance for FBMC-based uncoded TPSK is better than FBMC-based uncoded 4-QAM by 0.27 dB at BER = 10^{-3} and BER performance for FBMC-based coded TPSK is better than FBMC-based coded 4-QAM by 0.47 dB at BER = 10^{-3}.

4. Conclusion

In this paper, a new digital modulation scheme TPSK is applied with FBMC. It shows that OTPSK is compatible with FBMC and the BER performance of FBMC/OTPSK is better than FBMC/OQAM. In addition, TCC with rate =1/2 is introduced with FBMC/OTPSK, and results show that using FBMC/OTPSK modulation with TCC has a lower bit error rate and higher forward error correction than conventional FBMC/OQAM with BCC.

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