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A Review on Compressed Sensing Space-Time Frequency Index Modulation in OFDM System

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Abstract: **In wireless communication, orthogonal frequency division multiplexing (OFDM) plays a major role because of its high transmission rate. In space-time shift keying (STSK), the information is conveyed by both the spatial and time dimensions, which can be used to strike a trade-off between the diversity and multiplexing gains. On the other hand, orthogonal frequency division multiplexing (OFDM) relying on index modulation (IM) conveys information not only by the conventional signal constellations as in classical OFDM, but also by the indices of the subcarriers. In this review compressed sensing (CS) is studied in order to increase throughput and bit-error performance by transmitting extra information bits in each subcarrier block as well as to decrease the complexity of the detector.**

Keywords: **OFDM, MIMO, Space-Time Shift Keying (STSK), Frequency Index Modulation, Compressed Sensing (CS).**

I. INTRODUCTION

Now-a-days, OFDM is of great interest to researchers all over the world. In OFDM, the entire channel is spitted into many narrow parallel sub channels, so the duration of symbol is increased and the inter symbol interference (ISI) produced by thematic-path environments is reduced or eliminated. OFDM supports high data rate traffic because the incoming serial data stream is divided into parallel low-rate streams that are transmitted on orthogonal sub-carriers simultaneously [1].

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The available spectrum in an OFDM systemic divided into manifold sub-carriers and all these subcarriers are orthogonal to each other [3]. OFDM has been standardized for several applications, such as digital audio broadcasting (DAB), digital television broadcasting, wireless local area networks (WLANs), and asymmetric digital subscriber lines (ADSLs).The capability of OFDM system is improved using MIMO technique, which spatially multiplexes data streams via multiple antennas. MIMO–OFDM, the combination of both OFDM and MIMO technologies, is currently under study andis one of the most propitious candidates for future communication systems, ranging from wireless LAN to broad band access. The MIMO communication systems use multiple transmit and receive antennas, increase the data rate without increasing the bandwidth, increase the diversity, and improve the performance against fading channels using space–time codes [4]. It has been found that the capability of MIMO–OFDM systems grow linearly with the number of antennas, when optimal knowledge of the wireless channel is available at the receiver. The use of multiple antennas at the transmitter and receiver sides can significantly enhance the capacity and reliability of wireless links [5]. However, multi-antenna operation faces significant challenges due to complexity and cost of the hardware owing to the requirement of inter-antenna synchronization and maintenance of multiple radio-frequency (RF) chains. Spatial modulation (SM) is a relatively new modulation technique for multiple antenna systems which addresses these issues. This modulation technique was first proposed in [4], and later improved further in. Space shift keying (SSK) is another signalling technique which can be thought of as the special case of SM.

II. LITERATURE REVIEW

BrankaVucetic and Jinhong Yuan, in [1] provided a working knowledge of space-time coding and its application to wireless communication systems. Dipl.-Ing. BiljanaBadic, in [2] provided a unified theory of Quasi-Orthogonal Space-Time Block Codes (QSTBCs) for four transmit antennas and one (or more) receive antennas. K. Kumar and A. Mitra in [3] Estimated (MIMO) channels by Artificial Neural Network (ANN)s such as (Multi-Layer Perceptron (MLP)s). Kaleeswaran Rajeswari S. Jayaraman Thiruvengadam in [4] provided a hybrid channel estimator proposed for Multiple-Input-Multiple-Output orthogonal frequency- division multiplexing

(MIMO-OFDM) system. Sven Jacobsson in [5] showed that least-squares (LS) channel estimation combined with joint pilot And the processing of transmitted data represent the capacity which obtained in the single-user, single-receive-antenna case. Z. Ling and Z. Xianda in [6] performed channel estimation and equalization algorithm using three-layer artificial neural networks (ANNs) with feedback for Multiple-Input-Multiple-Output wireless communication systems. C. Çiflikli, A. TuncayÖzsahin and A. Çagri in [7] proposed an artificial neural network (ANN) channel estimation technique based on levenbergmarquardt training algorithm as an alternative to pilot based channel estimation technique for OFDM systems over Rayleigh fading channels. K. CharlyJomon and S. Prasanth in [8] extended sparse Bayesian learning (ESBL), a new method for multichannel compressive sensing for channel estimation in MIMO-OFDM. In [9] Nanda discusses and experimented the BER in multi-carrier OFDM.

III. OFDM SYSTEM

OFDM is a wideband wireless digital communication technique that is based on block modulation. With the wireless multimedia applications becoming more and more popular, the required bit rates are achieved due to OFDM multicarrier transmissions. Multicarrier modulation is commonly employed to combat channel distortion and improve the spectral efficiency. Multicarrier Modulation schemes divide the input data into bands upon which modulation is performed and multiplexed into the channel at different carrier frequencies so that information is transmitted on each of the sub carriers, such that the sub channels are nearly distortion less [9].

At the OFDM transmitter end, the N-point IFFT is taken for transmitted symbols. Taking the N-point FFT of the received samples, the noisy version of the transmitted symbols can be obtained in the receiver. N point FFT is used to convert the signal from time to frequency domain [10]. The input data is first mapped into a modulation scheme. The complex plane data is transformed to parallel format and IFFT transform is obtained to produce OFDM signal. The output data is converted to serial format and cyclic prefix is added. Reverse operations are carried out at the receiver end. Cyclic prefix is removed and N-point FFT is taken to retrieve the transmitted data. Following equation can be used for computing FFT and IFFT:

FFT

$$X(k) = \sum_{n=0}^{N-1} x(n)e^{-j2\pi nk/N} \quad \text{(i)}$$

Where (k=0,1,……,N-1)

IFFT

$$X(n) = 1/N \sum_{n=0}^{N-1} X(k)e^{j2\pi nk/N} \quad \text{(ii)}$$

Where (n = 0,1,……,N-1)

IV. SPACE SHIFT KEYING

Space Shift Keying (SSK) In SSK, a group of information bits are used to choose one transmit antenna, i.e., an m-bit sequence chooses one antenna from a total of $nt = 2m$ antennas.

A known signal (which is known to the receiver) is transmitted on this chosen antenna. The remaining $nt-1$ antennas remain silent. By doing so, the problem of detection at the receiver becomes one of merely finding out which antenna is transmitting. This leads to a significantly reduced complexity at the receiver.

The index of each transmit antenna represents a certain combination of information bits.

For example, with $nt = 4$, transmit antennas with indices 1, 2, 3, 4 can be mapped to bit sequences 00, 01, 10, 11, respectively. Therefore, at the receiver, detection of a certain transmit antenna index leads to conveying the group of information bits associated with that index. The spectral efficiency in SSK grows logarithmically with number of transmit antennas, i.e., log2 nt bits per channel use (bpcu).

A consequence of this type of spatial mapping is that number of transmit antennas has to be a power of 2. Let us take the known signal transmitted by the active antenna to be 1.

Then, for a SSK system with two transmit antennas, the possible signal set is given by $\mathbb{S}2 \equiv \{[1, 0] , [0, 1]T \}$. A zero in the signal vectors above is silence in the corresponding transmit antenna. In general, a SSK signal set for nt transmit antenna system is given by:

$$S_{nt} = \{S_j : j = 1, \dots\dots\dots, n_t\}$$
$$s.t. \quad S_j = [0, \dots..0,1,0, \dots..0]^T \quad \text{(iii)}$$

V. SPACE-TIME SHIFT KEYING

Space-time shift keying (STSK) has been regarded as an advantageous multifunctional multiple-input multiple-output (MIMO) technique because of its flexibility in providing both multiplexing and transmit diversity gains [4]. Compared to the conventional spatial modulation (SM) [11] and space-shift keying (SSK) [12], STSK exhibits both transmit and receive diversity gains instead of only attaining receive diverity gain, as in SM and SSK. Namely, STSK spreads information to both the spatial and time dimensions, where the information is mapped to the classic L-PSK/QAM symbols and additional information is transmitted by activating one out of Q dispersion matrices (DM). On the other hand, the distortion due to multipath fading is the main challenge in wideband fading channels, and often Multi-Carrier (MC) modulation is used for mitigating this distortion, which effectively converts the dispersive wideband channels into a number of parallel narrowband flat-fading sub channels [13].

Orthogonal frequency-division multiplexing (OFDM) is the most widespread MC modulation technique, as a benefit of its robustness in wideband channels and its low-complexity implementation. OFDM has been combined with STSK in [7,8], where it was shown that OFDM-aided STSK is capable of mitigating the performance degradation of SC-STSK operating in wideband channels [14].

VI. INDEX MODULATION FOR TRANSMIT ANTENNAS: SPATIAL MODULATION

SM is a novel way of transmitting information by means of the indices of the transmit antennas of a MIMO system in addition to the conventional M-ary signal constellations. In contrast to conventional MIMO schemes which rely either on spatial multiplexing to boost the data rate or spatial diversity to improve the error performance, the multiple transmit antennas of a MIMO system are used for a different purpose in an SM scheme. More specifically, there are two information carrying units in SM: indices of transmit antennas and M-ary constellation symbols. For each signalling interval, a total of

$$log_2(n_T) + log_2(M) \qquad \text{(iv)}$$

bits enter the transmitter of an SM system a, where $n_T$and$n_R$denote the number of transmit and receive antennas, respectively, and M is the size of the considered signal constellation such as M-ary phase shift keying (M-PSK) or M-ary quadrature amplitude modulation (M-QAM).

The log2 (M) bits of the incoming bit sequence are used to modulate the phase and/or amplitude of a carrier signal traditionally, while the remaining log2 (n_T) bits of the incoming bit sequence are reserved for the selection of the index (I) of the active transmit antenna which performs the transmission of the corresponding modulated signal (s). The receiver of the SM scheme has two major tasks to accomplish: detection of the active transmit antenna for the demodulation of the index selecting bits and detection of the data symbol transmitted over the activated transmit antenna for the demodulation of the bits mapped to M-ary signal constellation [15-20].

The main advantages of SM over classical MIMO systems can be summarized as follows:

- Simple transceiver design: Since only a single transmit antenna is activated, a single radio frequency (RF) chain can handle the transmission for the SM scheme. Meanwhile, inter-antenna synchronization (IAS) and inter-channel interference (ICI) are completely eliminated, and the decoding complexity of the receiver, in terms of total number of real multiplications performed, grows linearly with the constellation size and number of transmit antennas.
- Operation with flexible MIMO systems: SM does not restrict the number of receive antennas as the V-BLAST scheme, which requires n_R>n_T to operate with minimum mean square error (MMSE) detector.
- High spectral efficiency: Due to the use of antenna indices as an additional source of information, the spectral efficiency of SM is higher than that of single-input single-output (SISO) and orthogonal STC systems.
- High energy efficiency: The power consumed by the SM transmitter is independent from number of transmit antennas while information can be still transfered via these antennas. Therefore, SM appears as a green and energy-efficient MIMO technology.

VII. OFDM WITH INDEX MODULATION

IM concept can be considered for other communications systems apart from MIMO systems. For an instance, IM techniques can be efficiently implemented for the subcarriers of an OFDM system. OFDM-IM is a novel multi-carrier transmission scheme which has been proposed by inspiring from the IM concept of SM [21].

Similar to SM, in the OFDM-IM scheme, the incoming bit stream is split into index selection and M-ary constellation bits. According to the index selection bits, only a subset of available subcarriers are selected as active, while the remaining inactive subcarriers are not used and set to zero. On the other hand, the active subcarriers are modulated according to the M-ary constellation bits.

In other words, the information is conveyed not only by the data symbols as in classical OFDM, but also by the indices of the active subcarriers which are used for the transmission of the corresponding data symbols for the OFDM-IM scheme.

Considering an OFDM system with NF subcarriers, one can directly select the indices of active subcarriers similar to IM technique used for the transmit antennas of an MA-SM system [22].

However, the massive OFDM frames can provide more flexibility for the employment of IM techniques for OFDM-IM schemes compared to SM schemes. On the other hand, keeping in mind that NF can take very large values, such as 512, 1024 or 2048 as in LTE-A standard, there could be trillions of (actually more than a googol (10100) in mathematical terms) possible combinations for active subcarriers if index selection is applied directly [24,25].

As an example, assume that we want to select the indices of 256 active subcarriers out of NF = 512 available subcarriers, then, there could be 472.55 × 10^{150} possible different combinations of active subcarriers, which turn the selection of active subcarriers into an almost impossible task. Therefore, for the implementation of OFDM-IM, the single and massive OFDM-IM block should be divided into G smaller and manageable OFDM-IM subblocks each containing N subcarriers to perform IM, where NF = G × N [26,27].

For each subblock, K out of N available subcarriers can be selected as active according to the $p_1 = log_2\binom{N}{K}$ index selection bits where typical N values could be 2, 4, 8, 16, and 32 with 1 ≤ K < N. Please note that classical OFDM becomes a special case of OFDM-IM with K = N, that is, when all subcarriers are activated. The block diagrams of OFDM-IM scheme's transmitter and receiver structures are illustrated in Figs. 1 and 2 respectively.

As seen from Fig. 1 for each OFDM-IM frame, a total of

$$m = pG = (log_2\binom{N}{K} + Klog_2M)G \qquad \text{(v)}$$

bits can be transmitted where p = $p_1 + p_2$ and $p_2 = K\ log_2 M$. In Fig. 1 j_g and s_g denote the vector of selected indices and M-ary data symbols with dimensions K×1, respectively. First, OFDM-IM subblock creator forms the N×1 OFDM-IM subblocksx_g, g = 1, . . . , G, then the OFDM-IM block creator obtains the N_F × 1 main OFDM-IM frame x by concatenating these G OFDM-IM subblocks.

After this point, G×N block interleaving can be performed to ensure that the subcarriers of a subblock are affected by uncorrelated wireless fading channels. Finally, classical OFDM procedures such as inverse fast Fourier transform (IFFT), cyclic prefix (CP) insertion, and digital-to-analog (DAC) conversion are applied [28].

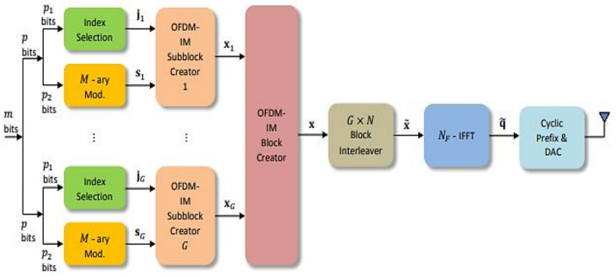

Fig. 1: OFDM-IM system Transmitter structure

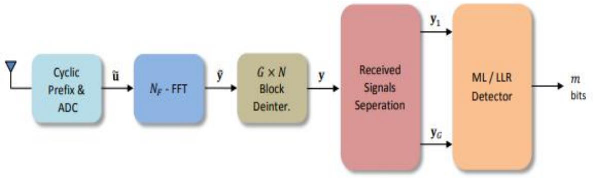

Fig. 2: OFDM-IM system Receiver structure

VIII. COMPRESSED SENSING

In recent years, compressed sensing (CS) [16-18] has attracted considerable attention as a typical example to recover the sparse signal from a small set of linear measurements. CS has been applied to various wireless communication applications by exploiting the sparsity of the target signal vector, such as channel estimation, interference cancellation and symbol detection. CS is first applied to OFDM-IM by Zhang et al. [19], where the CS-aided OFDM-IM is demonstrated to be capable of achieving a higher spectral efficiency and better error performance than the conventional OFDM-IM scheme over wideband channels [29].

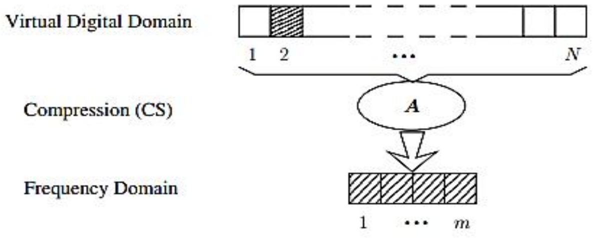

Fig. 3: Illustration of the CS scheme

We assume a multicarrier system employing M subcarriers [20,21]. The M subcarriers are divided into G groups, each of which contains m = M/G subcarriers. An L_b-length sequence of i.i.d. data bits is first split into G groups, each of which contains L = L_b/G = $L_1 + L_2$ bits. In each group, L_1 bits are mapped into an index symbol according to an index mapper μ_1: $\{0, 1\}^{L_1} \rightarrow Z$, where Z = {$Z_1$, . . . , Z_C } contains C = $2L_1$ index subsets, each of which is formed with the aid of K indices chosen from N available indices. Thereby, we have $L_1 = log_2C = log_2\binom{N}{K}$.

Let the c_{th} index subset of be denoted as Z_c = {Z_c(0), . . . , Z_c(K − 1)} ⊂ Z, where Z_c(k) ∈ Z N + for k = 0, . . . ,K −1. Let us assume that the gth group of data bits is mapped into the c_{th} candidate in Z. Then, for the sake of simplicity, let the g_{th} group of the index symbols be denoted as Ig = Z_c⊂ Z. On the other hand, the remaining L2 bits are mapped onto K classic APM symbols according to a rotated Q-ary QAM/PSK constellation.

IX. CONCLUSION

Index modulation is an emerging concept, in which extra information bits are mapped to the indices of multiple transmission resources such as the indices of antennas, subcarriers or time slots. It has been studied that by contrast, OFDM with IM (OFDM-IM)is a beneficial frequency-domain IM techniqueas compared to classical OFDM. In this survey, key premises and useful tips and tricks is also studied for designing compressed sensing (CS) based wireless systems. In this paper, a space-time frequency index modulation scheme relying on CS-aided is studied in order to reduce complexity detections for transmission over frequency selective channels. The information bits would be transmitted using space, time and frequency dimensions to improve the spectral efficiency as well as the BER performance.

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