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Research Article

Space Power Block Coding (SPBC): A Novel 6G Method for Providing High Throughput and Ultra-Reliability for Processing-limited Receivers

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***Abstract*—In this work, we introduce a new transmission method inspired by space-time block-coding (STBC) with orthogonal frequency division multiplexing (OFDM) to jointly improve spectral efficiency and reliability, while reducing receiver complexity, which is deemed as a critical requirement for processing-limited IoT devices. The newly developed transmission method, coined as space-power block-coding (SPBC), utilizes the superposition of specially precoded data streams to be transmitted to serve a single end-receiving device with two antennas, while keeping the receiver structure unchanged, thus making it compatible with any current or future modern smart end-devices. The proposed scheme objectives are to improve spectral efficiency, increase the link throughput, and enhance reliability for a single OFDM-based receiver. In particular, the user data streams are superimposed with intelligently designed pre-coders intending to cancel the intentionally introduced interference at the transmitter as well as the channel impact and effect at the receiver, while ensuring that the reception process is much simpler and way less complex. Moreover, we analyze the obtained comparative simulation results, where it is found that the performance of the proposed design is significantly higher than that of its conventional counterparts.**

***Index Terms*—MIMO, STBC, SPBC, OFDM, 5G, 6G, Superposition, Precoding, Reliability, Spectral Efficiency, IoT, V2X.**

I. Introduction

THE grand vision of vehicle-to-everything (V2X) communication supported by the sixth generation (6G) of wireless systems will be an instrumental element of future connected autonomous vehicles [1]. On the other hand, the Internet of Things (IoT) is a gigantic network of things ranging from simple sensors to smartphones, wearables, autonomous cars, and drones that are connected and used to collect and analyze data to perform actions. These low-cost sensing modules and more enhanced powerful devices are integral parts of IoT today. The diversity of such devices and associated applications result in heterogeneous data in various senses [2].

To improve the reception quality and meet the many requirements of IoT related applications in telecommunication systems, diversity techniques have widely been applied to wireless systems. A base station in a wireless network often serves tens to hundreds of users. It is, therefore, more economical to add equipment to base stations rather than the user devices. For this reason, transmit diversity schemes are very attractive [3]. In [3], S. M. Alamouti presented a simple transmit diversity scheme which improves the signal quality at the receiver on one side of the link by simple processing across two transmit antennas on the opposite side. The obtained diversity order is equal to the acquired diversity gain by applying maximal-ratio receiver combining (MRRC) with two antennas at the receiver.

In orthogonal space-time block codes (STBC), due to the decoding error probability being high, authors in [4] developed a linear transformation (precoding) solution of orthogonal STBC for reducing the probability of decoding error, when the transmitter knows channel covariance matrix. Particularly, the authors provided a closed form solution for multi-input single-output (MISO) systems and a numerical solution for the multi-input multi-output (MIMO) systems.

In practical wireless communication scenarios, the antennas available on the reception side are usually more restricted than the antennas on the transmitter side, whereas there is no such limitation in STBC. Therefore, in [5], a hybrid STBC scheme was proposed that exploits these two systems. The hybrid STBC technique involves two approaches: a pre-coding and a decision feedback detection method. By using the linear pre-coding matrix, performance can be enhanced and the interference can be canceled out by utilizing the decision feedback detection scheme.

In [6], a new scheme was investigated that integrates a linear pre-coder exploiting both the channel mean and transmit correlation with non-orthogonal space-time code systems. The precoder is based on pairwise error probability with minimized Chernoff bound on it. This precoder can be viewed as a multifunction beamformer and can converge to a single beam as the K factor increases. Usually, due to low minimum diversity and decoder's error propagation, there is a bit error rate (BER) performance degradation in vertical Bell-Labs layered space-time (VBLAST) MIMO system. On the other hand, even an STBC-integrated VBLAST system does not outperform the pre-coded VBLAST system [7]. Therefore, in [7], the authors developed a hybrid joint design that includes a pre-coder and its relevant decoder for the VBLAST-STBC system.

Conventionally, to obtain transmit diversity, multiple antennas are required, but due to possible physical constraints like in MIMO, diversity cannot be realized. However, cooperative communication solves this dilemma by enabling a single antenna to function as a virtual multiple antenna transmitter under sharing the available antennas [8]. To achieve high-

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performance authors in [8], utilize STBC with one transmit antenna, and pre-code the transmit symbols, thus, achieving high gain without loss in the transmission rate.

In [9], authors investigate unitary pre-coders using STBC for space-time coded orthogonal frequency division multiplexing (ST-OFDM) systems. Two-channel variations are assumed where in the case of LTI, optimal pre-coders are derived that are channel-dependent and greatly enhance the system performance, while in the time-varying case, channel variation causes inter-carrier interference (ICI) in the ST-OFDM system, ICI can be alleviated by properly designing the pre-coder which can average out the error variance.

Authors in [10] developed a multi-mode pre-coder design by varying the number of streams depending on the channel conditions and also proposed a design criterion of reducing the vector symbol error rate with an efficient algorithm to generate pre-coders. In [11], authors proposed a Zadoff-Chu matrix transform (ZCMT) based STBC MIMO-OFDM system with reduced peak-to-average power ratio (PAPR), to obtain low PAPR than Walsh-Hadamard transform (WHT) pre-coded STBC MIMO-OFDM systems and the conventional STBC MIMO-OFDM systems.

In [12], coordinated multi-point system STBC is implemented as a joint coding strategy with pre-coding user data comparative to channel state information (CSI) to improve spectrum utilization and edge user receptivity. The study in [13] presents an STBC dirty paper coding (DPC) system which includes maximum likelihood (ML), one-dimensional searching algorithm, and QR decomposition of channel matrix for gaining reliable performance. Channel on/off assignment while using the water filling algorithm to combat deep fading channel problem, and Tomlinson-Harashima precoding (THP) scheme for lowering the PAPR.

Authors in [14] proposed a combination of STBC, and spatial modulation with hybrid analog-digital beamforming for 60 GHz Millimeter-wave (mmWave) communications to take advantage of these schemes and avoid their drawbacks. In [15], [16], we proposed a modified STBC with a non-orthogonal superposition technique dedicated to serving multi-users by utilizing the inherent diversity and redundancy that exist in both time and space domains of STBC transmission scheme. In particular, purposely designed assistant signals are superimposed on top of the multi-user data during the two transmission time slots of STBC to intelligently cancel inter-user interference as well as channel fading at the receiving end device, while ensuring that the reception process is much simpler and less power-consuming than conventional systems.

As discussed above, the state-of-the-art in the light of pre-coding and classical STBC is not suitable for the requirements and challenges imposed by 6G. To address these necessities, in this paper, **we propose a novel transmission method, coined as Space-Power Block-Coding (SPBC), which can provide high throughput, ultra-reliability, elimination of inter-antenna and inter-symbol interference, physical layer security improvement, and diversity enhancement, while ensuring less complexity at the receiver as there is no need for doing equalization in the proposed method.**

The novelty and main contributions of the proposed method design can be explained as follows:

- Exploiting the STBC concept and the super positioning of user data streams in a novel manner to simultaneously complete the transmission of two symbols within just one single time slot rather than two as is the case with conventional STBC method.
- The completion of the transmission within just one time slot while serving the end user with the same transceiver resources enables achieving spectral efficiency enhancement by double compared to conventional STBC which requires at least two-time slots to complete the transmission. Consequently, the overall throughput gain is twice that of the conventional STBC.
- The design and utilization of special type of pre-coding matrices $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$ and $\mathbf{P_4}$ to eliminate interference by the time the signal reaches the receiver without forcing the receiver to do any extra processing like data signal combination or successive interference cancellation (SIC). Consequently, the processing complexity gets reduced at the received as well as the delay, thus making the proposed technique very suitable for low complexity IoT devices as the receiver is not required to do any extra processing.

In the subsequent sections, we will discuss the proposed transmission method, SPBC, the explain the proposed mathematical derivation behind the method, present the simulation results, and finally draw the conclusion.

II. Proposed System Model

The proposed system design is displayed in Fig. 1, where a transmitting base station equipped with two antennas is serving a single OFDM receiver with two antennas $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$. By exploiting the proposed SPBC transmission scheme, which will be explained in the next section, the superimposed data signals are simultaneously transmitted from two transmit antennas $\mathbf{A_{n_1}}$ and $\mathbf{A_{n_2}}$ in just one single time slot $\mathbf{t_1}$ instead of needing to complete the transmission within two-time slots $\mathbf{t_1}$ and $\mathbf{t_2}$ as is the case in the conventional STBC scheme.

Furthermore, we superimpose the specially designed pre-coders to data signals before transmission in each time slot at the transmitter. The channels between transmit and receive antennas are denoted by (H_{km}, which is the channel frequency response diagonal matrix with k_{th} receiver antennas and m_{th} transmit antennas. The channels are assumed to be multi-path Rayleigh fading with exponential decaying factor and are calculated by using channel sounding techniques exploiting the reciprocity od the channel in a time division duplex (TDD) system.

III. Proposed Transmission Method (SPBC) Design

According to the proposed system model as shown in Fig. 1, the mathematical algorithm is illustrated as follows: The two transmit antennas $\mathbf{A_{n_1}}$ and $\mathbf{A_{n_2}}$ simultaneously serve a single OFDM receiver with two antennas $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$ during just one single time slot instead of two different time slots, as the case in conventional STBC systems. The fact that the proposed

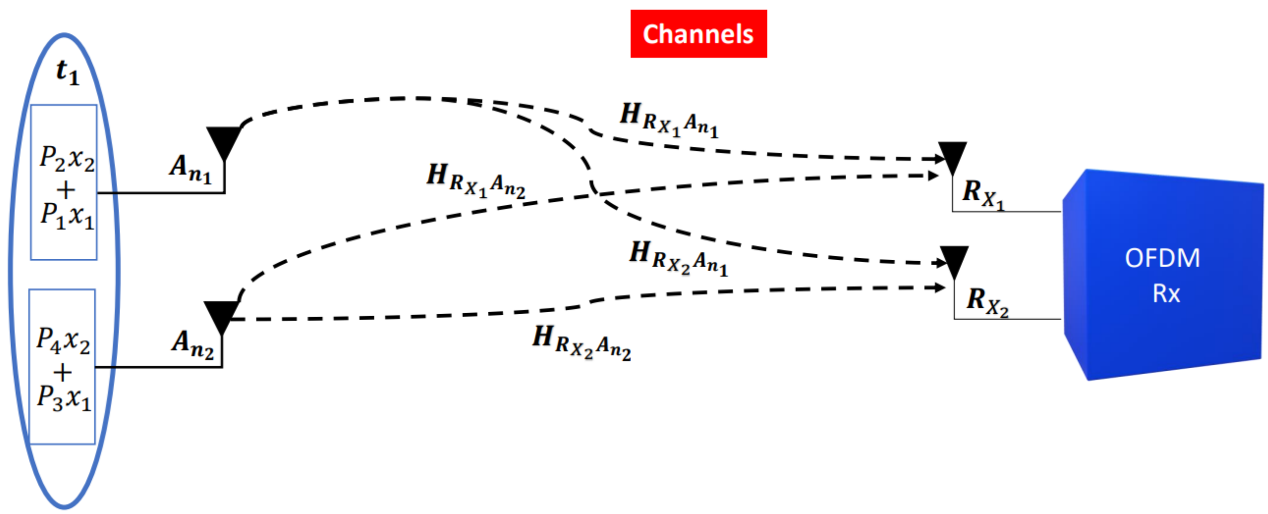

Fig. 1. Proposed SPBC system model serving a single OFDM receiver with same transceiver resources. When SPBC is used with OFDM, which is what is assumed in this paper, the precoding and superposition processes done on the transmitted signals will be implemented in the frequency domain before the IFFT block of an OFDM-based system to make the design less complex by exploiting the diagonal nature of the estimated channel frequency response for all the OFDM subcarriers

method can send two symbol vectors within one single time slot results in improving the spectral efficiency and throughput by double compared to traditional STBC systems. The total number of modulated symbols in one OFDM block is N_f and each data vector is $\mathbf{x_A} = [\mathbf{x_0}, \mathbf{x_1}, ..., \mathbf{x_{N-}}]^\mathbf{T} \in C^{[N\times 1]}$ and $\mathbf{x_B} = [\mathbf{x_0}, \mathbf{x_1}, ..., \mathbf{x_{N-1}}]^\mathbf{T} \in C^{[N\times 1]}$, respectively. The pre-coder matrices $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$ and $\mathbf{P_4}$ are designed based on the receiver channels and superimposed with the data to be transmitted. $y_{km}\in C^{[N\times 1]}$, $h_{km}\in C^{[N\times N]}$, and $n_{km}\in C^{[N\times 1]}$ represent the received signal, the channel response, and the additive white Gaussian noise (AWGN) between k_{th} receiver antenna and m_{th} transmit antenna, respectively.

1) Transmission and Reception Process: The superimposed transmitted signal from $\mathbf{A_{n_1}}$ is represented as

$$\mathbf{s_1} = \mathbf{P_1}\mathbf{x_1} + \mathbf{P_2}\mathbf{x_2}, \tag{1}$$

and the transmitted superimposed signal from $\mathbf{A_{n_2}}$ is given as

$$\mathbf{s_2} = \mathbf{P_3}\mathbf{x_1} + \mathbf{P_4}\mathbf{x_2}, \tag{2}$$

where $\mathbf{x_1}$ and $\mathbf{x_2}$ are frequency domain data vectors designed for $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$. Furthermore, $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$ and $\mathbf{P_4}$ are the superimposed pre-coder matrices that are the function of the each receivers' channel.

In time slot $\mathbf{t_1}$, $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$ receive the transmitted signals from antennas $\mathbf{A_{n_1}}$ and $\mathbf{A_{n_2}}$, which are given as

$$\mathbf{y^1_{R_{x_1}A_{n_1}}} = \mathbf{H_{R_{x_1}A_{n_1}}}\mathbf{s_1}, \tag{3}$$

where $\mathbf{H_{R_{x_1}A_{n_1}}}$ represents the channel's frequency response between $\mathbf{R_{x_1}}$ and antenna $\mathbf{A_{n_1}}$. Similarly, the received signal at $\mathbf{R_{x_1}}$ transmitted from $\mathbf{A_{n_2}}$ is represented as

$$\mathbf{y^1_{R_{x_1}A_{n_2}}} = \mathbf{H_{R_{x_1}A_{n_2}}}\mathbf{s_2}, \tag{4}$$

where $\mathbf{H_{R_{x_1}A_{n_2}}}$ is the channel frequency response between $\mathbf{R_{x_1}}$ and transmit antenna $\mathbf{A_{n_2}}$. The signal received at $\mathbf{R_{x_2}}$ from $\mathbf{A_{n_1}}$ is given as

$$\mathbf{y^1_{R_{x_2}A_{n_1}}} = \mathbf{H_{R_{x_2}A_{n_1}}}\mathbf{s_1}, \tag{5}$$

where $\mathbf{H_{R_{x_2}}A_{n_1}}$ represents the channel's frequency response between $\mathbf{R_{x_2}}$ and antenna $\mathbf{A_{n_1}}$. Similarly, the received signal at $\mathbf{R_{x_2}}$ which is transmitted from $\mathbf{A_{n_2}}$ is represented as

$$\mathbf{y^1_{R_{x_2}A_{n_2}}} = \mathbf{H_{R_{x_2}A_{n_2}}}\mathbf{s_2}, \tag{6}$$

where $\mathbf{H_{R_{x_2}A_{n_2}}}$ is the channel frequency response between $\mathbf{R_{x_2}}$ and transmit antenna $\mathbf{A_{n_2}}$.

The combined received signals at $\mathbf{R_{x_1}}$ transmitted from $\mathbf{A_{n_1}}$ and $\mathbf{A_{n_2}}$ are given as follows

$$\mathbf{y^1_{R_{x_1}}} = \mathbf{y^1_{R_{x_1}A_{n_1}}} + \mathbf{y^1_{R_{x_1}A_{n_2}}} + \mathbf{n^1_{R_{x_1}}}, \tag{7}$$

Now putting the values of $\mathbf{y^1_{R_{x_1}A_{n_1}}}$ and $\mathbf{y^1_{R_{x_1}A_{n_2}}}$ in (7) as

$$\mathbf{y^1_{R_{x_1}}} = \mathbf{H_{R_{x_1}A_{n_1}}}\mathbf{s_1} + \mathbf{H_{R_{x_1}A_{n_2}}}\mathbf{s_2} + \mathbf{n^1_{R_{x_1}}}, \tag{8}$$

In (8), $\mathbf{s_1}$ and $\mathbf{s_2}$ represent the superimposed transmitted signals and $\mathbf{n^1_{R_{x_1}}}$ is the AWGN at $\mathbf{R_{x_1}}$ during time slot $\mathbf{t_1}$. Substituting the values of $\mathbf{s_1}$ and $\mathbf{s_2}$ in (8) we get

$$\begin{aligned}\mathbf{y^1_{R_{x_1}}} &= \mathbf{H_{R_{x_1}A_{n_1}}}(\mathbf{P_1}\mathbf{x_1} + \mathbf{P_2}\mathbf{x_2}) \\ &\quad + \mathbf{H_{R_{x_1}A_{n_2}}}(\mathbf{P_3}\mathbf{x_1} + \mathbf{P_4}\mathbf{x_2}) + \mathbf{n^1_{R_{x_1}}}.\end{aligned} \tag{9}$$

Combining like terms after rearranging (9) we get

$$\begin{aligned}\mathbf{y^1_{R_{x_1}}} &= (\mathbf{H_{R_{x_1}A_{n_1}}}\mathbf{P_1} + \mathbf{H_{R_{x_1}A_{n_2}}}\mathbf{P_3})\mathbf{x_1} \\ &\quad + (\mathbf{H_{R_{x_1}A_{n_1}}}\mathbf{P_2} + \mathbf{H_{R_{x_1}A_{n_2}}}\mathbf{P_4})\mathbf{x_2} + \mathbf{n^1_{R_{x_1}}}.\end{aligned} \tag{10}$$

The first mathematical term of (10) is basically the desired term concerning and pertaining to $\mathbf{R_{x_1}}$, whereas the remaining other expressions are undesired and unwanted.

The combined received signals at $\mathbf{R_{x_2}}$ transmitted from $\mathbf{A_{n_1}}$ and $\mathbf{A_{n_2}}$ during time slot $\mathbf{t_1}$ are given as follows

$$\mathbf{y^1_{R_{x_2}}} = \mathbf{y^1_{R_{x_2}A_{n_1}}} + \mathbf{y^1_{R_{x_2}A_{n_2}}} + \mathbf{n^1_{R_{x_2}}}, \tag{11}$$

Now putting the values of $\mathbf{y^1_{R_{x_2}A_{n_1}}}$ and $\mathbf{y^1_{R_{x_2}A_{n_2}}}$ in (11) as

$$\mathbf{y^1_{R_{x_2}}} = \mathbf{H_{R_{x_2}A_{n_1}}s_1} + \mathbf{H_{R_{x_2}A_{n_2}}s_2} + \mathbf{n^1_{R_{x_2}}}, \tag{12}$$

In (12), $\mathbf{s_1}$ and $\mathbf{s_2}$ represent the superimposed transmitted signals and $\mathbf{n^1_{R_{x_2}}}$ is the AWGN at $\mathbf{R_{x_2}}$ in time slot $\mathbf{t_1}$. Substituting the values of $\mathbf{s_1}$ and $\mathbf{s_2}$ in (12), we get

$$\begin{aligned}\mathbf{y^1_{R_{x_2}}} &= \mathbf{H_{R_{x_2}A_{n_1}}}(\mathbf{P_1x_1} + \mathbf{P_2x_2}) \\ &\quad + \mathbf{H_{R_{x_2}A_{n_2}}}(\mathbf{P_3x_1} + \mathbf{P_4x_2}) + \mathbf{n^1_{R_{x_2}}}.\end{aligned} \tag{13}$$

Equation (13) can be rearranged and represented as

$$\begin{aligned}\mathbf{y^1_{R_{x_2}}} &= (\mathbf{H_{R_{x_2}A_{n_1}}P_1} + \mathbf{H_{R_{x_2}A_{n_2}}P_3})\mathbf{x_1} \\ &\quad + (\mathbf{H_{R_{x_2}A_{n_1}}P_2} + \mathbf{H_{R_{x_2}A_{n_2}}P_4})\mathbf{x_2} + \mathbf{n^1_{R_{x_2}}}.\end{aligned} \tag{14}$$

The second mathematical term of (14) is essentially the desired term pertaining to $\mathbf{R_{x_2}}$, whereas the other remaining expressions are the undesired and unwanted terms that need to be removed to get red of the interference.

Equations (10) and (14) represent the received signals at $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$ in time slot $\mathbf{t_1}$ respectively.

2) Designing Pre-coders: The superimposed pre-coders $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$ are inspired by the works [17], [18], [19], [20], [21]. The desired terms for $\mathbf{R_{x_1}}$ are $(\mathbf{H_{R_{x_1}A_{n_1}}P_1} + \mathbf{H_{R_{x_1}A_{n_2}}P_3})\mathbf{x_1}$. For $\mathbf{R_{x_2}}$, the desired expressions are $(\mathbf{H_{R_{x_2}A_{n_1}}P_2} + \mathbf{H_{R_{x_2}A_{n_2}}P_4})\mathbf{x_2}$. First we have to set up conditions according to the desired and unwanted terms at $\mathbf{R_{x_1}}$ and $\mathbf{R_{x_2}}$.

Condition for $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$ during $\mathbf{t_1}$:

To formulate the conditions for the pre-coders $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$, the first term in the equation (10) is equated to identity matrix $\mathbf{I}$ and also the unwanted second term is made equal to null matrix $\mathbf{O}$. Furthermore, the second expression in equation (14) is the required one, thus is equated to identity matrix $\mathbf{I}$, and the undesired first term is equated to null matrix $\mathbf{O}$ as given below

$$\mathbf{H_{R_{x_1}A_{n_1}}P_1} + \mathbf{H_{R_{x_1}A_{n_2}}P_3} = \mathbf{I}. \tag{15}$$

$$\mathbf{H_{R_{x_2}A_{n_1}}P_1} + \mathbf{H_{R_{x_2}A_{n_2}}P_3} = \mathbf{O}. \tag{16}$$

From the above-obtained two equations we can get a conditional system of mathematical equations for the model such as

$$\begin{cases}\mathbf{H_{R_{x_1}A_{n_1}}P_1} + \mathbf{H_{R_{x_1}A_{n_2}}P_3} = \mathbf{I}, \\ \mathbf{H_{R_{x_2}A_{n_1}}P_1} + \mathbf{H_{R_{x_2}A_{n_2}}P_3} = \mathbf{O}.\end{cases} \tag{17}$$

$$\mathbf{H_{R_{x_2}A_{n_1}}P_2} + \mathbf{H_{R_{x_2}A_{n_2}}P_4} = \mathbf{I}. \tag{18}$$

$$\mathbf{H_{R_{x_1}A_{n_1}}P_2} + \mathbf{H_{R_{x_1}A_{n_2}}P_4} = \mathbf{O}. \tag{19}$$

From the above-obtained two equations we can get a conditional system of mathematical equations for the model such as

$$\begin{cases}\mathbf{H_{R_{x_2}A_{n_1}}P_2} + \mathbf{H_{R_{x_2}A_{n_2}}P_4} = \mathbf{I}, \\ \mathbf{H_{R_{x_1}A_{n_1}}P_2} + \mathbf{H_{R_{x_1}A_{n_2}}P_4} = \mathbf{O}.\end{cases} \tag{20}$$

The above-mentioned two systems of mathematical equations can together be solved to get the values of the precoders that need to be used at the transmitter to make sure the interference completely gets eliminated by the time the signal reaches the receiver due to using $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$ such as

$$\begin{cases}\mathbf{P_1} = -\mathbf{H_{R_{x_2}A_{n_2}}} \\ (\mathbf{H_{R_{x_1}A_{n_2}}H_{R_{x_2}A_{n_1}}} - \mathbf{H_{R_{x_1}A_{n_1}}H_{R_{x_2}A_{n_2}}})^{-1}, \\ \mathbf{P_3} = -\mathbf{H_{R_{x_2}A_{n_1}}} \\ (\mathbf{H_{R_{x_2}A_{n_1}}H_{R_{x_1}A_{n_2}}} - \mathbf{H_{R_{x_1}A_{n_1}}H_{R_{x_2}A_{n_2}}})^{-1}.\end{cases} \tag{21}$$

$$\begin{cases}\mathbf{P_2} = -\mathbf{H_{R_{x_1}A_{n_2}}} \\ (\mathbf{H_{R_{x_1}A_{n_1}}H_{R_{x_2}A_{n_2}}} - \mathbf{H_{R_{x_1}A_{n_2}}H_{R_{x_2}A_{n_1}}})^{-1}, \\ \mathbf{P_4} = -\mathbf{H_{R_{x_1}A_{n_1}}} \\ (\mathbf{H_{R_{x_1}A_{n_1}}H_{R_{x_2}A_{n_2}}} - \mathbf{H_{R_{x_1}A_{n_2}}H_{R_{x_2}A_{n_1}}})^{-1}.\end{cases} \tag{22}$$

Using the above derived system of mathematical equations shown in (21) and (22), the undesired/unwanted terms and the channels effects are eliminated during the reception of one single time slot instead of two time slots $\mathbf{t_1}$ and $\mathbf{t_2}$ as is the cas in conventional STBC Method. Therefore, through (21) and (22) the equations (10) and (14) can be modified as

$$\mathbf{y^1_{R_{x_1}}} = \mathbf{x_1} + \mathbf{n^1_{R_{x_1}}}. \tag{23}$$

$$\mathbf{y^1_{R_{x_2}}} = \mathbf{x_2} + \mathbf{n^1_{R_{x_2}}}. \tag{24}$$

IV. Differences of the Proposed Method (SPBC) from Conventional NOMA

One might look at our proposed method and say that there seem to be some similarities with the conventional NOMA proposed in the literature [22]. Therefore, we thought that it would be useful to dedicate a section to talk about that. Motivated by this, the differences can be summarized in the following main points:

- NOMA is mainly aimed and specifically designed for multi-user scenarios to improve the overall system spectral efficiency; however, our proposed method is specifically focused on the single user scenario to improve the link spectral efficiency per device.
- NOMA always needs to employ successive interference cancellation (SIC) to remove the interference of far user from the near users. However, our proposed method does not use SIC at all, but rather depend on a specially designed precoded utilized at the transmitter to make

the signal free of interference by the time it reaches the receiver, which does not need to do any extra processing to get rid of the interference.

- NOMA can only work when there is a pathloss power difference between the near and far users, but completely fails when both receivers are in the same range. However, our proposed method can work in all scenarios including the worst-case one, where both receivers have more or less the same distance from the base station transmitter.
- NOMA needs power allocations to separate the far user signal from that of the near user; however, this is not a condition for our proposed techniques because it does not require a pathloss difference between users to make the transmission successful. In the contrary to that, our proposed technique can work without the need for power allocations that is needed to make the SIC successful in decoding and separating the signals, rather it depends on deploying a specially designed precoders that can cancel interference intelligently. This is so because NOMA operates without precoding, while our techniques utilizes precoders to cancel interference.
- NOMA is not inherently secure at the physical layer because the transmitted signals are not designed based on the channel variations of the receiver, aside from the fact that the near user has to decode the far user data signal before it decodes its own, which jeopardize the security of the system and make it vulnerable to the eavesdropping type of attacks. contrarily, our propsoed method is inherently secure at the physical layer because the signal data precoding are designed to be dependent on the channel specifications of the receiver.

V. Physical Layer Security Notion for SPBC

In present wireless communication systems, providing security is a must due to the ever-increasing number of users and IoT devices. However, security shouldn't be the cause of degradation of the system's performance. Authors in [23], propose a practical precoded orthogonal space-time block coding (POSTBC) method. An optimum matrix is used to precode the space-time codewords to minimize the error rate only for the legitimate user. According to the acquired results, there is and existing security gap region in the resulting BER performance as a consequence of using POSTBC. The authors also propose precoding along with a partial pre-equalizing (PCPPE) hybrid method, in which a new precoder is proposed, as a result of the original precoder, and a new unitary matrix that can map Bob's channel amplitudes into a 2D orthonormal matrix.

In [24], the authors have proposed physical layer security (PLS) scheme that can further enhance the security of STBC-OFDM via signals space diversity (SSD). This scheme works under the impression that the legitimate user has less error than the eavesdropper, even when the worst-case scenario occurs where the unauthorized receiver can somehow capture the interleaving strategy compromised by the transmitter and legitimate receiver. In the study [25], authors exploit the chaos communication technique and present an improved chaos MIMO scheme where PLS is realized with additional channel coding gain. In particular, a chaotic modulation symbol is multiplied by the data to be transmitted, and at the receiver, joint detection and chaos decoding is performed by maximum likelihood decoding (MLD).

On the contrary, our proposed SPBC method provides the PLS security solution against internal and external security vulnerabilities with less complexity. The systems of equations presented by (21), and (22) illustrate the values of pre-coders $\mathbf{P_1}$, $\mathbf{P_2}$, $\mathbf{P_3}$, and $\mathbf{P_4}$. In addition, these pre-coders are basically function of the wireless channel variations and characteristics thus yielding the desired outcome for security. Accordingly, the internal and external physical layer security threats can be avoided while securing the transmission of legitimate data to the intended receiver.

VI. Simulated Results

In this section, we evaluate and investigate the performance of the proposed SPBC method by adopting metrics such as bit error rate (BER), link throughput (TER), and peak to average power ratio (PAPR). The parameters considered in the computer simulation analysis of SPBC by using MATLAB software are given in Table I.

TABLE I
MATLAB Simulation Parameters

Channel	Multipath Rayleigh Fading Channel
Channel Length	9
Cyclic Prefix (CP)	9
IFFT/FFT Size	64
Number of Iterations	10000
Number of Symbols	9000000
Modulation Type	BPSK
Signal to noise ratio in dB	0-25 dB
Channel Delay	[0 3 5 6 8]
Channel Power Profile	[0 -8 -17 -21 -25]
Guard Interval Length	16

It is assumed that we have an OFDM system consisting of N_f=64 subcarriers with a CP size equals to the channel delay spread length L to eliminate inter-symbol interference (ISI). As shown in Table I, the channels between the transmitting and receiving antennas are assumed to be multi-path Rayleigh fading channels with a number of taps L=9.

As seen in Fig. 2, the BER performances depicted by Rx1-BER and Rx2-BER are much less (approximately at 15 dB SNR) than the conventional OFDM, theoretical STBC (with nTX=2, nRx=1), conventional Alamouti STBC (with nTX=2, nRx=1), and the transmit diversity with pre-coding (with nTX=2, nRx=1). The proposed design can ensure the best performance in comparison to conventional designs, and the case of PLS due to different wireless channels, the legitimate receiver can easily and securely receive and decode the transmitted signals.

In Fig. 3, the illustrations of the TER performances for SPBC, conventional STBC (with nTX=2, nRx=1), and transmit diversity with pre-coding (with nTX=2, nRx=1) are presented. The individual TER performances for the Rx1 and Rx2 are greater than the conventional STBC and similar to

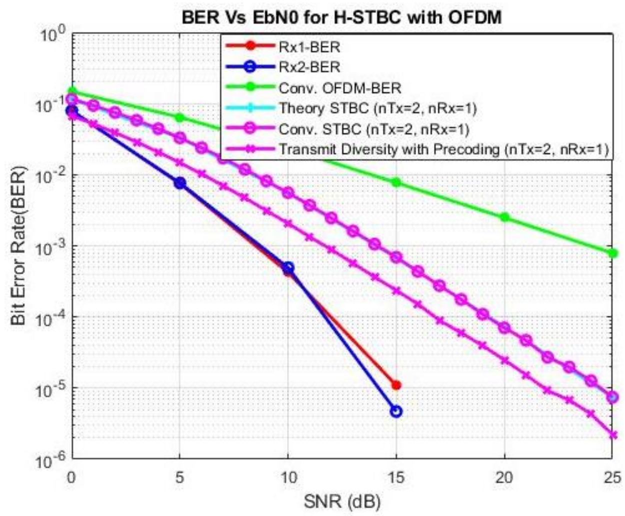

Fig. 2. Bit error rate (BER) performance of the proposed SPBC method compared to the conventional scheme.

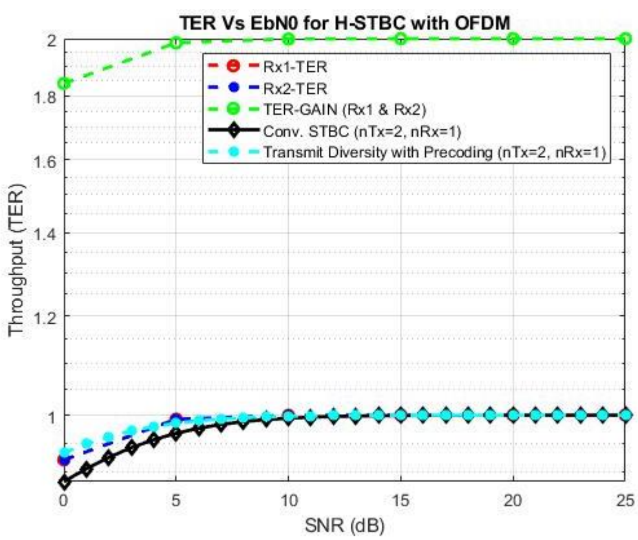

Fig. 3. Throughput (TER) performance of the proposed SPBC method compared to the conventional system.

transmit diversity. Furthermore, the overall performance gain for the SPBC denoted by TER-GAIN (Rx1 & Rx2) is doubled that of the conventional STBC and transmit diversity.

VII. Conclusion

In this article, we investigated the reliability performance of the introduced SPBC technique with the achievable double throughput for a single user. The results obtained during the computer simulations depicted that the proposed design outperforms the conventional comparable wireless systems. In addition, due to the resulting BER performance as a consequence of SPBC, the security against internal and external threats is realized. Moreover, the PAPR performance illustrates that the proposed design can also achieve better results in power saving compared to the conventional OFDM. Considering future works, this scheme can be extended to multiple users, and the security aspect can be further enhanced.

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