Space Time and Frequency Adaptive Switching in Nakagami Fading Channel

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Abstract— The combination of orthogonal frequency division multiplexing (OFDM) signal processing and multiple-input multiple-output (MIMO) is regarded as a promising solution for enhancing the data rates of next-generation wireless communication systems operating in frequency- selective fading environments. To realize this extension of OFDM with MIMO, a number of changes are required in the baseband signal processing. With respect to this, an overview is given for the necessary changes, including time and frequency synchronization, channel estimation and diversity gain. In this paper, all three possible variants namely receiver, transmitter and combined selection are compared to each other and the results of numerical simulations are presented. A switching technique is presented that selects an appropriate transmission scheme between the STBC-OFDM and SFBC-OFDM assuming Nagakami fading model in the channel. Based on the proposed criteria, it is observed that for large delay spread channels, STBC yields superior performance while SFBC results in better performance under high Doppler frequency.

Index Terms—*MIMO, STBC-OFDM, SFBC-OFDM, Nakagami Fading channel, adaptive switching*

I. INTRODUCTION

The main challenge in developing reliable high data rate mobile communications systems is to overcome the detrimental effects of frequency-selective fading channels. A number of space-time coded OFDM transmitter diversity techniques have been proposed for high data rate wireless communications [1]. Space-time and space-frequency block-coded OFDM (STBC-OFDM and SFBC-OFDM) systems are efficient means of achieving near optimum diversity gain in frequency-selective fading channels. STBC - OFDM and SFBC - OFDM [3] were proposed in literature as the combining scheme. STBC-OFDM assumes that channel gain is constant during the *n* OFDM symbols in n_{TX} transmit antennas system. SFBC-OFDM assumes that channel gain is constant during the n_{TX} successive sub channel within one OFDM symbol in n_{TX} transmit antennas system. Thus it shows the strength in fast time varying channels while being vulnerable to the frequency selectivity. Use of space-time codes and space-frequency with multiple transmit antennas has generated a lot of interest for increasing spectral efficiency and improved performance in wireless communications. The orthogonal design of Alamouti, Tarokh et al[4], Naguib and Seahadri [3] is still somehow the main reference which lead to simple, optimal receiver structure. Adaptive switching between space-time and space-frequency in order to maximize the SNR in Rayleigh fading channels has been proposed in [5]. The combination of these schemes offers both immunity to ISI and high capacity. Here we have focused our work on Nakagami fading model which is one of the most versatile, in the sense that it has greater flexibility and accuracy in matching some experimental data than Rayleigh, lognormal, or Rician distributions.

The remainder of this paper is organized as follows; in section II, spatial diversity with time and frequency block coding are detailed. Channel Model is proposed in section III, followed by Space-Time/Space-Frequency Block Coding in Nakagami fading channel in section IV .Section V is dedicated to the simulation results and finally in section VI our contributions are concluded.

II. SPATIAL DIVERSITY WITH TIME AND FREQUENCY BLOCK CODING

An optimal STF Space-Time-Frequency code needs to simultaneously code across space, time and frequency. However, OFDM provides a set of independent flat channels and consequently ST or SF coding techniques can be used on a per-ton basis. A serially concatenated, outer convolutional code can then be used to harness the benefits of coding across frequency. This process of concatenating an outer bit-level code and an inner spatial processing technique substantially reduces the complexity of the resulting STF code, [6]. The use of ST/SF coding techniques provides us with degrees of freedom in design that can be exploited to improve the link performance. The simple OFDM model is extended to space-time/space-frequency (STBC/SFBC)-OFDM with N_t transmit and N_r receive antenna as shown in Figure 1.

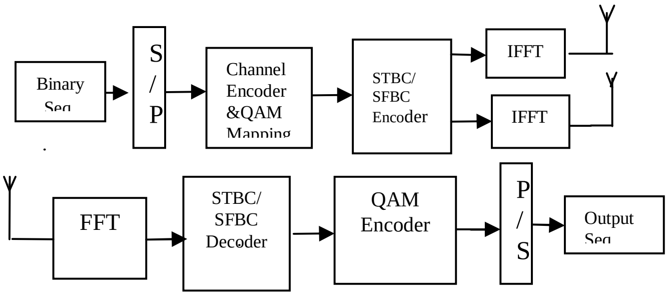

Figure 1. simplified concatenated channel coding with STBC/SFBC-OFDM system

The ST/SF coded symbols are encoded first and then concatenated with channel coding to further combat channel impairments. Each coded vector X_i is then passed through an IFFT block and cyclic-prefixed. The prefixed signals are then passed through their respective antennas. Each transmitted stream will undergo the influence of multipath fading and additive white Gaussian noise. At the receiver, cyclic prefix is removed and FFT is performed to recover the received symbols. These symbols can be estimated using maximum likelihood decoding or by a simple zero forcing scheme. The symbols are then demodulated and decoded and the recovered bits are then compared with the transmitted bits for BER measurement.

III. CHANNEL MODEL

In this section we consider a MIMO channel. A point-to-point communication system of N_T transmitter and N_R receiver antennas is shown in Figure 1. This system can be represented by following discrete time model;

$$\begin{bmatrix} y_1 \\ \vdots \\ y_{Nr} \end{bmatrix} = \begin{bmatrix} h_{11} & \cdots & h_{1Nt} \\ \vdots & \ddots & \vdots \\ h_{Nr} & \cdots & h_{NrNt} \end{bmatrix} \begin{bmatrix} x_1 \\ \vdots \\ x_{Nt} \end{bmatrix} + \begin{bmatrix} n_1 \\ \vdots \\ n_{Mr} \end{bmatrix} \quad (1)$$

Or simply as $y = Hx + n$. Here x represents the transmitted symbol, n is the noise vector, and H is the matrix of channel gains. We assume a channel bandwidth of B And complex Gaussian noise with zero mean and covariance matrix $\sigma_n^2 I_{Nr}$, where typically $\sigma_n^2 = N_0 B$ .For simplicity, given a transmit power constraint P we will assume an equivalent model with a noise power of unity and transmit power $P / \sigma_n^2 = \rho$,where ρ can be interpreted as the average SNR per receive antenna under unity channel gain. This power constraint implies that the input symbols satisfy

$$\sum_{i=1}^{Nt} E[x_i x_i^*] = \rho \qquad (2) .$$

In the system design, we consider discrete Nakagami fast fading MIMO channel models. In the transmitter, a data stream is demultiplexed into N_T independent sub streams. Each sub stream is encoded into transmit symbols using a modulation scheme (e.g. BPSK, M-QAM, etc.) at symbol rate 1/T sym/sec with synchronized symbol timing [7].

In the Nakagami flat fading model, The baseband N_R dimensional received signal vector

$$r(K) = [r_1(K), r_2(K), ..., r_{N_R}(K)]^T \qquad (3)$$

at sampling instant k may be expressed as

$$r(K) = H.x(k) + n(K) \qquad (4)$$

Denotes the transmit symbol vector with equally distributed transmitted power across the transmitted signal. Here, the superscript T is transposition. H denotes the $N_T * N_R$ channel matrix, whose elements h_{mn} is the channel gain from the m_{th} transmit antenna to the n_{th} receive antenna, and they are assumed to be independent and identically distributed circularly symmetric complex Gaussian random variables with zero-mean and unit-variance, having uniformly distributed phase and Nakagami distributed magnitude. A circularly symmetric complex Gaussian random variable is a random variable $c = a + jb$, in which a and b are independent and identically distributed (i.i.d) real Gaussian distributed as $(0, \sigma^2 / 2)$. A commonly used channel model in MIMO wireless communication systems is a block fading (also called quasi-static) channel model where the channel matrix elements, which are i.i.d complex Gaussian (Nakagami fading) random variables, are constant over a block and change independently from block to block. We drop the index k for the channel gain. The elements of the additive noise vector are assumed to be also white i.i.d complex Gaussian random variables with zero-mean and unit-variance. From this normalization of noise power and channel loss, the averaged transmitted power which is equal to the average SNR at each receive antenna is to be minimum [3, 7]. Now we consider the Nakagami fading model for the 2 transmitter and 2 receiver cases which we use in our simulations. The generalization to more than 2 transmit or receive antennas is straightforward. The Nakagami channel model for this case is given by [7]

$$H = \sqrt{\frac{K}{K+1}} H_F + \sqrt{\frac{1}{K+1}} H_V = \sqrt{\frac{K}{K+1}} \begin{bmatrix} e^{j\theta_{11}} & e^{j\theta_{12}} \\ e^{j\theta_{21}} & e^{j\theta_{22}} \end{bmatrix} + \sqrt{\frac{1}{K+1}} \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix} \quad \textbf{(5)}$$

is a fixed matrix (i.e. fixed for each block of a block fading channel) consisting of phase elements corresponding to line-of-sight

(LOS) the component and H_V is the Nakagami flat-fading matrix (as described above). K is the K-factor of the Nakagami distribution which is proportional to the strength of the LOS component. The Nakagami model was suggested before as a first order approximation to the Nakagami channel which under certain reasonable assumptions it gives an accurate approximation to the Nakagami channel. The assumptions when using this model are as follows: (i) the distance between the antennas is sufficient; (ii) the subscriber unit is mobile and possibly changing orientations. With respect to the base station, under these assumptions it is reasonable that the phases of the LOS component arriving at the different receiver antennas are random and uncorrelated. The measure delay and fading caused by multipath, where each Nakagami fading is generated by using the Jake's fading model, which compromises using random uniformly distributed Phase and Nakagami distribution. Channel model can be described as:

$$h_k = N(0,\frac{\sigma_k^2}{2}) + jN(0,\frac{\sigma_k^2}{2}),\quad \sigma_k^2 = (1-\exp(-T_S/T_{rms}))\exp(-kT_S/T_{rms}) \qquad (6)$$

IV. SPACE-TIME/FREQUENCY BLOCK CODING IN NAKAGAMI FADING CHANNEL

STFBC-OFDM is a good solution for a blind channel. In case of knowing channel state information, STFBC-OFDM estimation is not the optimal solution. We can improve the performance by switching the STBC-OFDM and SFBC-OFDM according to the channel characteristics. Spatial diversity is a widely applied technique for enhancing the wireless performance, since it greatly reduces the detrimental effects of multipath fading. Space-time coding (STC) provides an efficient solution to extract diversity by designing specific codes for OFDM system that incur minimal, and in most of the cases no sacrifice, in bandwidth efficiency.

Here, we propose the switching criterion using the channel condition and its corresponding performance features of the STBC-OFDM and SFBC-OFDM. The design and performance criteria of STBC /SFBC was first derived based on narrowband environments where the channel delay spread is normally much smaller than the symbol duration. The criteria are diversity gain which describes the asymptotic slope of the error rate versus SNR coding gain which does not affect the slope of the performance. The broadband wireless communication channels typically suffer from frequency selectivity. Using ST codes designed for flat fading over frequency selective channels is suboptimal because they fail to take advantage of the available frequency diversity. Moreover, when the delay spread becomes relatively high, the coding gain decreases considerably due to ISI and causes high performance degradation. Hence, additional processing is generally required to improve the performance of ST codes over selective fading channels [5].

Fig. 2 depicts a block diagram of the proposed system that adaptively switches between STBC-OFDM and SFBC-OFDM. The system consists of a transmitter with two antennas and a receiver with one antenna. The receiver estimates the channel state information and decides the appropriate transmission mode by using the proposed criteria. At the transmitter, the system switches between STBC-OFDM and SFBC-OFDM according to the feedback information from the receiver. The feedback path that informs the system of the mode and time/frequency synchronization is assumed to be perfect.

A ST code on frequency selective channels can achieve at last the same diversity gain as that on frequency flat channels, provided that maximum likelihood decoding is performed at the receiver [8]. This means that an optimal ST code on frequency selective fading channels may achieve a higher diversity gain on a flat channel, as the diversity gain of the former is N_{TX} N_{RX} L, which is L time higher than the diversity gain of flat channels. The ML decoding is prohibitive complex which leaves a reasonable option to improve the performance of STC on frequency selective channels by eliminating the ISI, frequency selective channels can be converted in to flat and optimal ST code for flat channels can be applied for selective channels. Adaptive equalizers provide a conventional approach to mitigate ASI. The main drawback of this method is high receiver complexity due to the need of employing a MIMO equalizer. OFDM solves this problem by dividing the entire channel into many parallel flat sub-channels, thereby removing the ISI and simplifying the receiver structure.

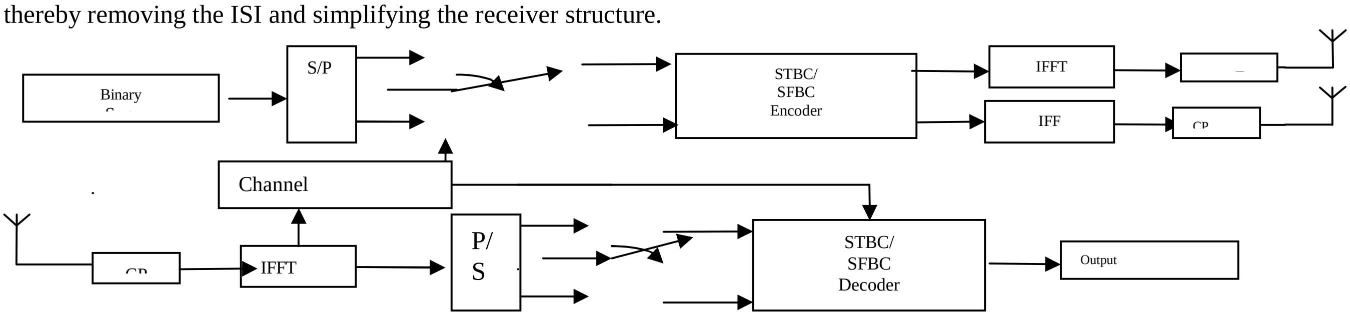

Figure 2. Block diagram of the adaptive switching systems

V. SIMULATION RESULTS

Comparison of STBC-SFBC/OFDM adaptive Switching in Nakagami fading Channel has been done using simulation parameters mentioned below. Considering the IEEE 802.11 (a) based WLAN standard, the following system parameters were used for simulations,

Parameter	Number of Subcarriers	Guard interval	Number of Tx antennas	Number of Rx antennas	Modulation	Symbol duration	Channel BW
value	64	16	2	1	4 QAM	34 μs	5MH

To generate the selective fading channel, the normalized Doppler and the normalized root mean square delay spread are uniformly 0.01 to 0.08 and from 1.5 μs to 8.5 μs . The aim of adaptive Switching with Criterion I, correlation of channel, is to improve the error rate performance of wireless systems, resulting in higher robustness to fading and increased coverage. Adaptive Switching methods are enabled by switching between different MIMO modes to reduce error rate for fixed data rate transmissions.

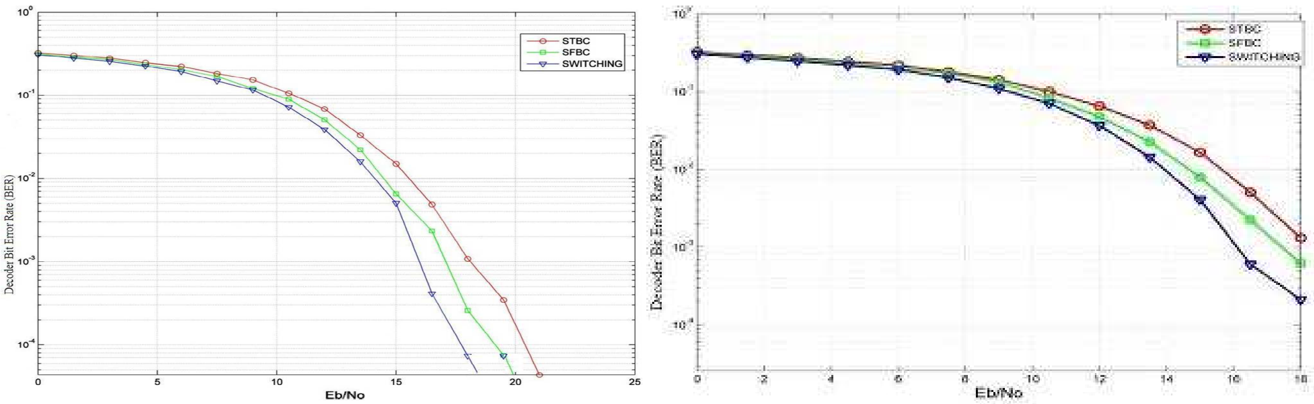

Figure 3. Comparison of STBC, SFBC and adaptive Switching a. under the Rayleigh Channel with gain 1-2, b. the Nakagami Channel with gain 2-3

To achieve the same data rate with different transmission modes, Figure 3.a shows the advantage of the proposed switching scheme over conventional schemes in terms of BERs. At the BER of 3×10^{-3}, the proposed technique exhibited SNR gains of 1 dB and 2 dB over the pure STBC-OFDM and SFBC-OFDM, respectively. As we can see using the Nakagami channel fading model Figure 3.b in this work shows better improvement in data rate in comparison to Rayleigh channel model was used in previous works. Although the Nakagami has more complexity than the Rayleigh channel model, it shows better performance.

VI. CONCLUSION

Multiple-Input Multiple-Output (MIMO) techniques in conjunction with orthogonal frequency division multiplexing (OFDM) will inarguably play an important role in the fruition of future wireless systems, promising higher data rates and affluent multi-media contents. For spatially uncorrelated MIMO systems, transmitter diversity is one of the most effective techniques, in particular, for OFDM based systems addresses the issue of achieving full diversity (spatial and multipath) with (STBC)/SFBC.

The advantage of using the Alamouti coding is partitioning the channel therefore as we transmit symbols, no interference occurs at the receiving end. This is the greatest advantage of use of the Alamouti coding since we do not need any complex receivers. The simple Maximum Likelihood detectors are enough to provide the optimum detection. We have explained an adaptive switching spatial mode consisting of ST-OFDM and SF-OFDM transmissions. Here we showed that the employment of the switched transmission techniques (between STBC and SFBC) plus using OFDM, provides us with additional diversity gain, that improve system performance by decreasing the bit error rate (BER) in existence of measured delay and fading, caused by multipath in Nakagami fading channels.

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REFERENCES

[1] S.M. Alamouti, “A simple transmit diversity technique for wireless communications,” IEEE J. Sel. Areas Common., vol.16, no.8, pp.1451–1458, 1998.
[2] M.R. Nakhai. Multicarrier transmission Centre for Telecommunications Research, King’s College London, Strand, London WC2R 2LS, UK.
[3] R. Bhatnagar, R. Vishwanath, and Vaibhav Bhatnagar “Performance Analysis of Space-Time Block Codes in Flat Fading MIMO Channels with Offsets” Hindawi Publishing Corporation EURASIP Journal on Wireless Communications and Networking, Volume 2007.
[4]G. Bauch, “Space-time block codes versus space-frequency block codes,” in Proc. IEEE Vehicular Technology Conference, pp. 567- 571,May 2003.
[5]K. Lee, Y. Kim and J. Kang “A Simple Adaptive Switching Scheme Between STBC-OFDM and SFBC- OFDM Systems”, IEICE Trans. Comm, 2008.
[6]P. PT Vanathi PT, “Optimized Multi-User Resource Allocation Scheme for OFDM - MIMO System Using GA & OGA”, IETE Tech Rev; 25:175-85, 2008.
[7]M. Debbah, “Short Introduction to OFDM”, [online] http://www.supelec.fr/d2ri/flexibleradio/cours/ofdmtutorial.pdf.
[8]A. Lodhi, “Space-Time Block Coding and Cyclic Delay Diversity for OFDM Mc-CDMA” PhD thesis 2007.