Space Time Turbo Coded OFDM with Joint Transmit and Receive Antenna Selection

Piotr Remlein and Tansal Gucluoglu

Abstract—**This paper discusses the performance of antenna selection technique in space time turbo coded MIMO-OFDM systems. Multiple-input multiple-output (MIMO) technology can either increase the data rate through spatial multiplexing or improve the reliability through diversity. Space-time turbo codes (STTC) have been proposed to provide robust communications in MIMO wireless environment. STTC technique incorporates the methods of transmitter diversity and channel coding to provide significant reduction of error rates over the traditional communication systems. The orthogonal frequency division multiplexing (OFDM) is a modulation method designed to mitigate multipath distortion and frequency selectivity of wireless channels at high data-rate transmissions. The MIMO-OFDM technology supports the advantages of both the MIMO system and the OFDM technique. In practice, a major impediment in MIMO-OFDM technology is the cost of hardware, because every antenna element requires a complete radio frequency (RF) chain to transmit signal over that element. In many (size and power constrained) mobile applications, it is desirable to have less RF units in multiple antenna systems which can be possible with antenna selection technique. In this paper, joint transmit and receive antenna selection for a space-time turbo coded MIMO-OFDM system is investigated. As the selection criterion, maximization of signal to noise ratio at the receiver is used for per-tone and all-tone selection methods. The simulation results show that the studied system improves performance by achieving significant diversity gains which makes it attractive for the next generation wireless standards.**

Index Terms—**space time turbo codes, MIMO transmission, OFDM modulation, antenna selection**

I. INTRODUCTION

FUTURE wireless communication system designs are dealing with the need of providing high-rate data communications to meet the requirements of new multimedia services. In order to provide robust communications in wireless environment, it is common to use multiple antenna systems (shortly referred as MIMO systems). MIMO technology can either increase the data rate through spatial multiplexing or improve the reliability through diversity.

Theoretically, the capacity of a MIMO system increases linearly with the number of transmit and receive antennas.

To improve the transmission quality in MIMO communication systems, the space-time codes (STC) have been proposed [1], [2], [3]. Space time codes can be based on simple block codes, trellis codes or turbo codes and are usually designed to achieve full diversity available in the system and as much coding gain as possible. Space time turbo codes (STTC) are very effective techniques that are constructed from the parallel concatenation of two recursive systematic convolutional codes with a pseudo-random interleaver between them. STC systems have been widely studied in the literature. However, in practice, the main drawback in STC systems is the increased cost of hardware since every antenna element requires a complete radio frequency chain for transmission. Similarly, the computational complexity at the receiver can prohibit the use of powerful STTC systems with large number of antennas. Considering the size and power constrained mobile devices, it is desirable to have low complexity transceivers. In this case, the technique named antenna selection can be employed to reduce the actively used antenna elements. Antenna selection (AS) [4] can be a useful method to decrease hardware and software complexity in multiple antenna systems. Based on a predetermined criterion such as maximization of signal to noise ratio (SNR), minimization of error rate or maximization of capacity, only some of the available antennas can be selected and used at each transmitted frame. There are several antenna selection methods studied in the literature. Antenna selection can be applied at the transmitter or receiver or jointly on both sides and it has been shown that the achievable diversity order does not degrade even if there are channel estimation errors [5], [6].

In recent years, there has been increasing interest in applying antenna selection to MIMO systems with OFDM scheme [7]. The orthogonal frequency division multiplexing – OFDM is a modulation method used to mitigate multipath and to combat the frequency selectivity of wireless channels at high data-rate transmissions. Integrating OFDM with MIMO is considered as a strong contender for the next generation wireless systems. A MIMO-OFDM technology is a part of the current wireless communications standards e.g. IEEE 802.11n [8], WiMAX (IEEE 802.16) [9] and 3GPP Long Term Evolution (LTE) [10]. The technology, MIMO-OFDM supports the advantages of both the MIMO system and the OFDM technique. Specifically, these are the high data rate wireless transmission with OFDM and the increased system capacity of MIMO. In MIMO-OFDM system, an information data stream at each transmit antenna is sent over a number of narrowband subcarriers. In this system, the antenna selection technique is a more complex problem than that in MIMO system. In MIMO-OFDM system, we can perform antenna selection algorithm for each tone of OFDM signal (per-tone method) or for all tones (all-tone method). Several methods have been proposed for selecting the optimal antenna subset for MIMO-OFDM. One method developed in [11] involves searching all possible antenna sets to maximize the MIMO-OFDM capacity. This

Piotr Remlein is with Poznan University of Technology, Poznan, Poland, remlein@et.put.poznan.pl

Tansal Gucluoglu is with Kadir Has University, Istanbul, Turkey, tansal@khas.edu.tr

method has high computational complexity and therefore is not attractive for practical use. In the literature, OFDM technique can be used with STCs in order to achieve high data rates while keeping the error rates low. In [12], STC-OFDM system is analyzed, and pairwise error probability (PEP) is derived which can help designing of new codes. It is shown that using STC-OFDM in frequency selective channel one can achieve full diversity order. In [13], a new space time – frequency coding for OFDM over frequency – selective fading channels is studied and it is shown that this technique can be capable of maximum diversity and high coding gain. Although there are considerably many works on STC-OFDM systems, only a few papers explored antenna selection in STC-OFDM systems. With the motivation of decreasing complexity in STC-OFDM systems, AS can be a preferable solution to have more practical transceivers. In [14], the performance of MIMO AS for these systems is analyzed to show that full diversity can be achieved with receive antenna selection. Receive antenna selection for MIMO-OFDM systems with channel estimation error is analyzed in [15]. In [16], Alamouti coded OFDM system with per-tone transmit antenna selection is analyzed and some power constraints to improve performance are developed in [17]. In [18], bulk versus per-tone transmit antenna selection is compared in MIMO-OFDM system and some important insights into codeword construction and performance analysis are presented. The performance of combined bulk and per-tone transmit antenna selection in uncoded OFDM systems is investigated in [19] and shown that the new scheme does not degrade the coding and diversity gains. STC-OFDM with joint transmit and receive antenna selection is presented in [20] where the simple Alamouti scheme [2] is not powerful enough to achieve most of the available diversity. Most of the previous studies have considered some analytical results to investigate performance. However, in order to understand the performance effects of antenna selection bit error rates should be compared in different scenarios.

In this paper, the performance of space-time turbo coded OFDM systems with joint transmit and receive antenna selection is explored over quasi-static frequency selective Rayleigh fading channels. We consider selection of the best antennas to maximize the received power for each subcarrier or for all subcarriers or combined selection. Only receiver is assumed to know the channel state information and performance comparison of different selection are presented. In Section II, some aspects of antenna selection methods are described. The analyzed system model and analytical considerations are presented in Section III. In the fourth section, numerical results are provided and finally conclusions are given in Section IV.

II. Antenna Selection Methods

Antenna selection is becoming an increasingly desired solution for the drawbacks of coded transmission in multiple antenna systems while not degrading the performance significantly. Since it only uses a fraction of the available antennas via few RF circuits, it results in both smaller units consuming less power and smaller delays caused by detection algorithms at the receiver.

It can be applied by firstly estimating the channel at the receiver, for example by using some pilot symbols transmitted and received over all available antennas by multiplexing. The antennas at transmitter and/or receiver can be selected by using a desired criterion such as maximization of SNR or capacity or minimization of error rates. Fig. 1 illustrates the block diagram of the MIMO-OFDM system with transmit and receive antenna selection. Since the received power is a common term in capacity and error rate expressions and resulting in easier analysis and implementation it has been widely preferred [21]. Once the selection is completed, the transmission can be carried out via selected antennas and simple RF switches until the selected antennas need to be changed according to the time varying channel coefficients. Clearly antenna selection may not be useful in highly mobile systems resulting in fast fading channels.

There are several antenna selection methods which can be categorized into three types: transmit antenna selection, receive antenna selection, or joint (i.e. transmit and receive antenna) selection [21]. Obviously, receive antenna selection is the simplest as it can be easily applied after channel estimation and usually preferable in downlink where the mobile unit is required to be small and power-efficient.

Transmit antenna selection requires the knowledge of channel coefficients or simply the indices of antennas selected and feedback by the receiver. It can be preferable for mobile units in uplink transmission. Clearly, employing antenna selection jointly at the transmitter as well as at the receiver can give the best performance and lowest operation complexity while increased computational complexity of selection process.

Antenna selection in MIMO OFDM systems can be employed with the consideration of subcarriers at each antenna to be used in actual transmission. For example, all subcarriers can use the same set of antennas and thus simply called "all-tone" selection or alternatively, antennas can be chosen independently for each subcarrier, named "per-tone" selection. Obviously all-tone selection method is simpler and it is more meaningful from the perspective of reducing complexity of MIMO transceivers. However, per-tone selection performs better as it has more options to make the best use of the coefficients of frequency selective fading channel. According to system specifications, selection can be based on a group of subcarriers or hybrid techniques can be used where first all-tone then per-tone selections are applied. Recent research on antenna selection has been increasing and mostly focusing on decreasing selection complexity and investigation of performance in different scenarios.

III. System Model

In the studied MIMO transmission, OFDM modulated symbols are transmitted from M_S transmit antennas which are selected from M possible candidates at the transmitter over the frequency selective fading channel having L taps and then received from N_S antennas which are selected from N available candidates at the receiver. The antennas are selected based on the maximization of the received SNR. It is assumed that channel state information (CSI) is perfectly known at the

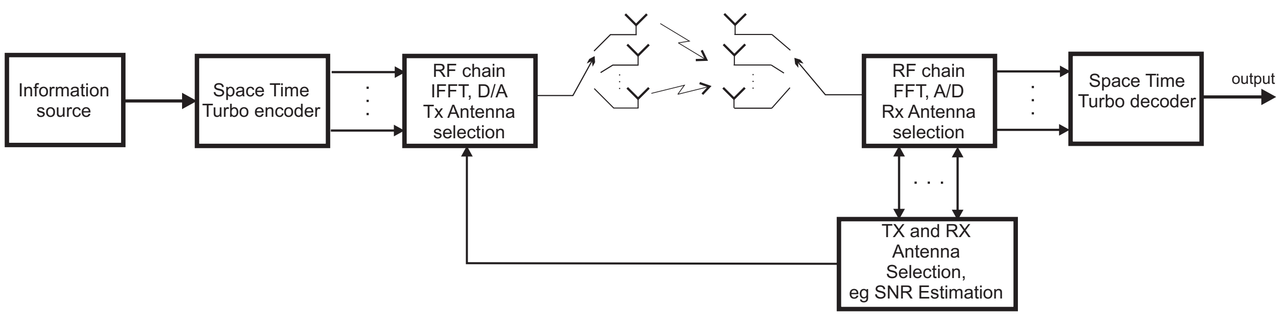

Fig. 1. Block diagram of the MIMO-OFDM system with transmit and receive antenna selection and optionally with space time coding

receiver to be used for selection and decoding and only the indices of the selected transmit antennas are fed back. The block diagram of the STTC-OFDM system with AS is shown in Fig. 1.

The simplified received signal at the output of the MIMO OFDM channel can be written as

$$Y_n[k] = \sum_{m=1}^{M_S} H_{n,m}[k] X_m[k] + W_n[k] \tag{1}$$

where $X_m[k]$ represents the transmitted data symbol from the k-th subcarrier ($k = 1, 2, ..., K$), and K shows the total number of subcarriers. $W_n[k]$ is zero mean i.i.d additive white complex Gaussian noise sample belonging to the n'th ($n = 1, 2, ..., N_S$) antenna. $H_{n,m}[k]$ denoting the channel coefficients between the n'th receive and m'th transmit antennas can be obtained by the discrete Fourier transformation as follows

$$H_{n,m}[k] = \sum_{l=0}^{L-1} h_{n,m}[l] e^{\frac{-j2\pi lk}{K}} \tag{2}$$

Here $h_{n,m}[l]$ is a zero-mean independent Gaussian distributed complex random variable, L shows the number of nonzero channel taps ($l = 0, 1, ..., L$). We assume proper cyclic extension and perfect synchronization.

To generate channel matrix $\mathbf{H}$, we used the narrowband Kronecker model presented in [22]. To calculate the correlation coefficients between the antennas in the transmitting as well as in the receiving array, we followed the approach in [22]. The channel model is based on the cluster model, where tap-dependent and cluster-dependent signal delay and power properties are characterized. Also, angular spread (AS), angle-of-arrival (AoA), and angle of departure (AoD) values are assigned to each tap and cluster that agree with values reported in the [23]. To compute a channel matrix H, we use a method that employs correlation matrix and i.i.d. matrix (zero-mean unit variance independent complex Gaussian random variables). The correlation matrix for each tap is based on the power angular spectrum (PAS) with angular spread AS. To calculate the numerical values of correlation matrices we use the Laplacian PAS shapes proposed in [22].

The channel model describes the propagation conditions, for example: multipath fading, and the Doppler phenomenon.

In the simulations we used the channel model B. This model has two clusters: the first one with the paths delays from 0 to 40 ns in10 ns steps, the second cluster with paths delays from 20 to 80 ns in 10 ns steps. These clusters have 5 and 7 paths, respectively. The signal paths delayed with 20, 30 and 40 ns (relative to the main path) occur in the both clusters.

Similar to [1], pairwise error probability (PEP) upper bound for the MIMO OFDM system [12] for a specific channel matrix $\mathbf{H}$ (containing all channel coefficients for all n, m, k values) can be written as:

$$P(\mathbf{X} \to \widehat{\mathbf{X}}|\mathbf{H}) \le \exp\left(-\frac{d^2\left(\mathbf{X}, \widehat{\mathbf{X}}\right)\rho}{8M}\right) \tag{3}$$

In the above expression the $\mathbf{X}$ represents the transmitted codeword and $\widehat{\mathbf{X}}$ denotes the decoded codeword. Similar to [5], PEP can be written as

$$P(\mathbf{X} \to \widehat{\mathbf{X}}|\mathbf{H}) \le \exp\left(-\frac{\rho}{8M}\|\mathbf{HB}\|^2\right). \tag{4}$$

$\mathbf{B}$ represents the codeword difference matrix, and the rank of it determines the diversity and eigenvalues of square of it determine the coding gain. The major difference is the application of channel coding in frequency domain instead of coding in time. Based on the above expression, the PEP derivation in [5] can be applied to MIMO OFDM system by following the similar lines of the lengthy PDF derivation and averaging over the distribution of the selected channel coefficients. Therefore, based on studies presented in [5] and [12], we can claim that full diversity order *NML* can be obtained if a strong space time coding is used in an OFDM system. The achievable diversity order of NML is also shown in [24] where PEP for STC over frequency selective fading channel is derived even with the assumption of imperfect channel estimation. In the literature, turbo coding is shown to provide enough diversity order in fading systems to obtain low error rates. Therefore we consider turbo coding for multiple antenna OFDM system.

In Fig. 2, the block diagram of the space time turbo encoder [3] is given. The encoder consists of a turbo encoder followed by a symbol interleaver and multiplexer. Each of STTC encoders operates on a block consisting of groups of m information bits. Input sequences of binary vectors $[c_1, ..., c_m]$ is transformed by the convolutional encoders which are shown in Fig. 3. One specific property of this scheme is that it can utilize M-ary modulation alphabet unlike many turbo schemes working on binary inputs. The details of the operation can be seen in [3].

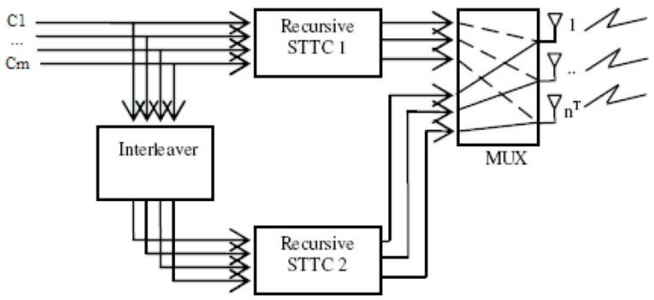

Fig. 2. Block diagram of the space time turbo encoder

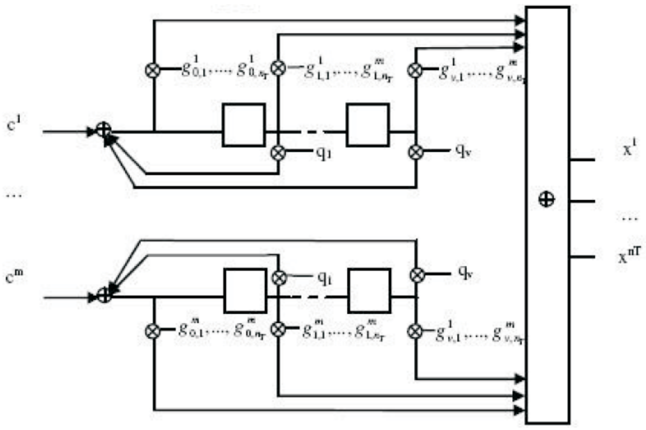

Fig. 3. Block diagram of a recursive STTC encoder for M-ary modulation

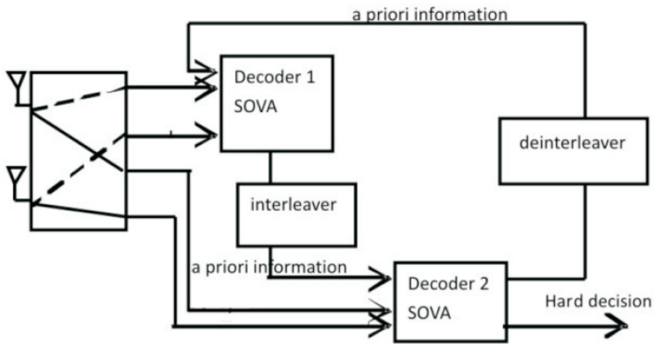

Fig. 4. Space-Time Turbo Decoder

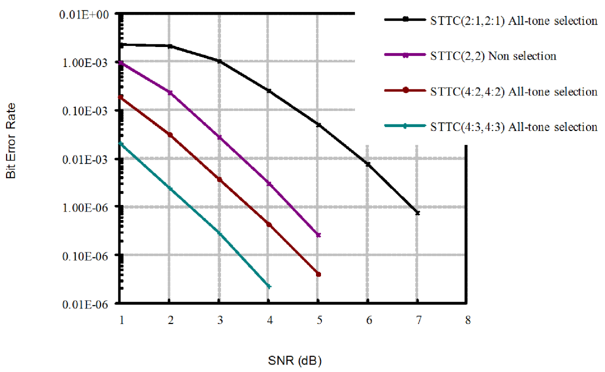

Fig. 5. STTC-OFDM system with all-tone transmit/receive antenna selection

In Fig. 3, the block diagram of a recursive convolutional encoder is given. The memory cells are capable of storing symbols and multipliers and adders can perform M–ary multiplication and addition operations respectively. Since we consider QPSK signaling the coefficients in the figure can be taken from the set {0,1,2,3} as explained in [3].

At the receiver side, there are n_R antennas. The signal received by each antenna is demultiplexed into two vectors, contributed by the recursive STTC 1 (upper) and recursive STTC 2 (lower) encoder, respectively. In the receiver, decoder 1 and decoder 2 (Fig. 2) use the iterative Soft Output Viterbi Algorithm (SOVA) [25]. It selects maximum likelihood path on the trellis diagram with a-priori received symbols probability taken into consideration.

In this paper, two different antenna selection methods are employed with STTC-OFDM system and our major focus is the comparison of performance results as discussed in the next section. The first selection method is called all-tone selection which performs the selection by maximizing the received power considering all OFDM sub-carriers. The second method is called per-tone selection where the best antennas are selected for each sub-carrier individually.

IV. Simulation Results

In this section, the simulation results of the STTC-OFDM system with joint transmit/receive antenna selection are provided. The notation "$(M; N)$" is used to denote M total antennas at the transmitter and N total antennas at the receiver. "$(M : M_S), (N : N_S)$" notation represents the system where M_S antennas are selected from M transmit antennas and N_S antennas are selected from N receive antennas. The space time coded bits are modulated by using QPSK signaling and OFDM with $K = 64$ sub-carriers. Bit error rate (BER) plots are shown for the STTC-OFDM system described in the previous section. Transmitted packet length has been set to 1000 bytes. Simulation system applies B transmission channel model [23]. We compare all-tone and per-tone antenna selection performances.

In Fig. 5, the performance of the STTC-OFDM system with all-tone selection is depicted. We observe that the (2:1,2:1) selection performs worse than the (2,2) system by about 3 dB at 10^{-4} BER. However, when we compare the systems (4:2;4:2) and (4:3,4:3) with the (2;2) system without antenna selection then there are about 1 dB and 3 dB SNR gains, respectively, at the bit error rate of 10^{-4}.We observe that even though the simplest all-tone selection is used, the diversity gains are quite high.

In Fig. 6, (2:1,2:1) and (4:2,4:2) all-tone selection is compared with per-tone selection cases. Comparing the no-selection (2,2) with (2:1,2:1) all-tone selection and (2:1,2:1) per-tone selection case, there is approximately 2.5 dB SNR gain and 0.1 dB gain at 10^{-4} BER, accordingly. Comparing the (4:2,4:2) per-tone antenna selection with (4:2,4:2) all-tone selection there is 2.5 dB SNR gain at 10^{-6} BER. Obviously, there are considerable performance improvements with antenna selection and with stronger coding like STTC in

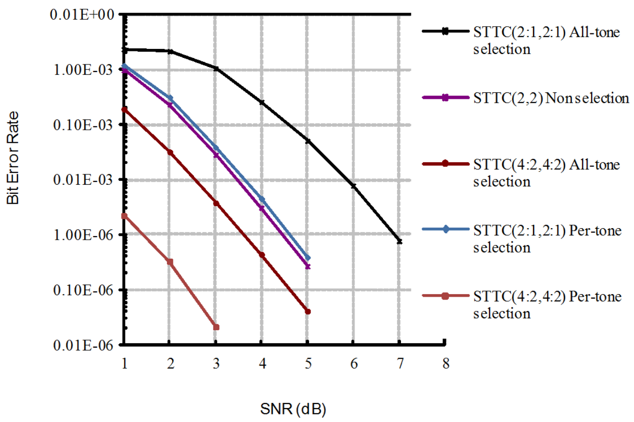

Fig. 6. Comparison of all-tone and per-tone selection methods in STTC-OFDM system

MIMO OFDM systems. As expected, we observe that antenna selection gains with per-tone selection can be larger than all-tone method.

V. Conclusion

In this paper the antenna selection methods for MIMO transmission are described and space-time turbo coded MIMO-OFDM system with joint transmit/receive antenna selection is investigated. The performances with all-tone and per-tone antenna selection methods are obtained via computer simulations and compared. Per-tone selection has the best performance and achieves high diversity gains at the cost of increased computational complexity. Simulation results verify that STTC-OFDM with transmit and receive antenna selection can decrease error rates significantly by exploiting high diversity orders. Therefore, the considered transmission model can appear in the next generation high speed OFDM based systems.

References

[1] V. Tarokh, N. Seshadri, and A. R. Calderbank, "Space time codes for high data rate wireless communication: performance criterion and code construction," *IEEE Trans. Inf. Theory*, vol. 44, pp. 745–764, Mar. 1998.

[2] S. M. Alamouti, "A simple transmit diversity technique for wireless communications," *IEEE J. Sel. Areas Commun.*, vol. 16, no. 8, Oct. 1998.

[3] Y. Hong, J. Yuan, Z. Chen, and B. Vucetic, "Space time turbo trellis codes for two, three, and four transmit antennas," *IEEE Trans. Veh. Technol.*, vol. 53, no. 2, pp. 318–328, 2004.

[4] S. Sanayei and A. Nosratinia, "Antenna selection in mimo systems," *IEEE Commun. Mag.*, vol. 42, no. 10, pp. 68–73, Oct. 2004.

[5] T. Gucluoglu and T. Duman, "Performance analysis of transmit and receive antenna selection over flat fading channels," *IEEE Trans. Wireless Commun.*, vol. 7, no. 8, pp. 3056–3065, Aug. 2008.

[6] T. Gucluoglu and E. Panayirci, "Performance of transmit and receive antenna selection in the presence of channel estimation errors," *IEEE Commun. Lett.*, vol. 12, no. 5, May 2008.

[7] M. Collados and A. Gorokhov, "Antenna selection for mimo-ofdm wlan systems," in *Proc. of PIMRC*, 2004, pp. 1802–1806.

[8] "IEEE 802.11n wireless local area networks," online, http://grouper.ieee.org/groups/802/11/.

[9] *IEEE Standard for Local and Metropolitan Area Networks; part 16: Air Interface for Fixed Broadband Wireless Access Systems*, IEEE, 802.16-2004 part 16, Oct. 2004.

[10] *Technical Specification Group Radio Access Network; Evolved Universal Terrestrial Radio Access (E-UTRA)*, 3GPP, 36.213 V8.2.0, Mar. 2008.

[11] Z. Tang, H. Suzuki, and I. B. Collings, "Performance of antenna selection for MIMO-OFDM systems based on measured indoor correlated frequency selective channels," in *Proc. of ATNAC*, Dec. 2006.

[12] B. Lu and X. Wang, "Space time code design in OFDM systems," in *Proc. of Global Telecom. Conf.*, vol. 2, 2000, pp. 1000–1004.

[13] Z. Liu, Y. Xin, and G. Giannakis, "Space-time-frequency coded ofdm over frequency-selection fading channels," *IEEE Trans. Signal Process.*, vol. 50, no. 10, Oct. 2000.

[14] I. Bahceci, T. Duman, and Y. Altunbasak, "Performance of MIMO antenna selection for space-time coded OFDM systems," in *Proc. of IEEE Wireless Com. Net. Conf. (WCNC)*, Atlanta, GA, Mar. 2004, pp. 987–992.

[15] A. Narasimhamurthy and C. Tepedelenlioglu, "Antenna selection for MIMO OFDM systems with channel estimation error," *IEEE Trans. Veh. Technol.*, vol. 58, pp. 2269–2278, 2009.

[16] J. Coon and M. Sandell, "Analysis of per-tone transmit antenna selection in OFDM systems with alamouti coding," in *Proc. of 7'th Int. Symp. Wireless Comm. Syst.*, 2010, pp. 164–168.

[17] M. Sandell and J. Coon, "Per-subcarrier antenna selection with power constraints in OFDM systems," *IEEE Trans. Wireless Commun.*, vol. 8, no. 2, Feb. 2009.

[18] H. Zhang and R. Nabar, "Transmit antenna selection in MIMO OFDM systems: bulk versus per-tone selection," in *Proc. of IEEE Int. Conf. Comm.*, 2008, pp. 4371–4375.

[19] J. Coon and M. Sandell, "Combined bulk and per-tone transmit antenna selection in OFDM systems," *IEEE Commun. Lett.*, vol. 15, no. 5, May 2010.

[20] S. Cinar, T. Gucluoglu, and M. E. Celebi, "Space-time coded OFDM system with transmit and receive antenna selection," in *Proc. of Future Network and Mobile Summit, FUNEMS*, 2010, pp. 1–6.

[21] S. Sanayei and A. Nosratinia, "Antenna selection in MIMO systems," *IEEE Commun. Mag.*, no. 10, pp. 68–73, Oct. 2004.

[22] J. Kermoal, L. Schumacher, K. Pedersen, P. Mogensen, and F. Fredriksen, "A stochastic MIMO radio channel model with experimental validation," vol. 20, no. 6, Aug. 2002.

[23] S. Loyka and G. Tsoulos, "Estimating MIMO system performance using the correlation matrix approach," *IEEE Commun. Lett.*, vol. 6, no. 1, pp. 19–21, Jan. 2002.

[24] *IEEE 802.11 Wireless LANs, TGn Channel Models*, IEEE 802.11-03/940r4, May 2004.

[25] L. Cong, W. Xiaofu, and Y. Xiaoxin, "On SOVA for nonbinary codes," *IEEE Commun. Lett.*, vol. 3, no. 12, pp. 335–337, Dec. 1999.

Piotr Remlein received the M.Sc. and the Ph.D. degrees from Poznan University of Technology (PUT), Poznan, Poland in 1991 and 2002 respectively. He has been employed at PUT since 1992, currently as an Assistant Professor at the Chair of Wireless Communications.

His scientific interests cover wireless networks, communication theory, error control coding, cryptography, digital modulation, trellis coded modulation, continuous phase modulation, mobile communications, digital circuits design. Dr. Remlein is the author of more than 70 papers, which have been presented at national and international conferences, and published in the communication journals. He also acts as a reviewer for international and national conference and journal papers. He is the member of The Institute of Electrical and Electronics Engineers (IEEE) Communications Society and IEEE Information Theory Society.

Tansal Gucluoglu received the B.S. degree from Middle East Technical University, Ankara, Turkey in 1997, the M.S. degree from Syracuse University in 2001 and the Ph.D. degree from Arizona State University in 2006, all in electrical engineering. He also worked as an R&D Engineer in industry between 1997 and 2001 in Ankara and Syracuse. Since 2006, he has been an Assistant Professor at the Department of Electronics Engineering, Kadir Has University, Istanbul. His research interests include channel coding, iterative receivers, multiple antenna and relay systems for wireless communications.