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Turbo-Coded V-BLAST/MAP MIMO System

Alaa H. Al Habbash[1]; Ammar M. Abu-Hudrouss[2]

Faculty of Engineering, Islamic University of Gaza, Palestine.[1]

Associate Professor of Communications, Islamic University of Gaza, Palestine.[2]

Abstract—Multiple Input Multiple Output (MIMO) systems can greatly increase the spectral efficiency. There is a need to design detection algorithm that can recover the transmitted signals with acceptable complexity and using suitable coding system to get high performance. In this paper, several MIMO detection techniques with Turbo coding were introduced and evaluated in terms of Bit Error Rate. VBLAST with Maximum A posteriori (MAP) detection techniques is introduced for Turbo coded MIMO system.

Index Terms—MAP; VBLAST; MIMO; MMSE; Turbo Coding

I INTRODUCTION

Multiple-Input-Multiple-Output (MIMO) systems are integral technology in the implementation for the fourth and fifth generation wireless systems. The advantages of MIMO system include high capacity, improved error performance, and interference suppression[1].

However, the high complexity associated with MIMO technology is the main limitation for some applications [2]. It is known that the computational complexity of any optimal, joint detection and decoding scheme for Multiple Input Multiple Output (MIMO) systems grows exponentially with the burst size [2-4]. In order to solve the detection problem in MIMO systems, research has focused on suboptimal receiver models which are powerful in terms of error performance and in the same time are practical for implementation purposes [2, 3].

Different transmission technique can be used with MIMO systems such as Space-Time Codes, (STC)[5] and the Vertical Bell Labs Space-Time Architecture (V-BLAST)[6]. STCs are used for diversity gain while VBLAST is used for capacity advantage.

There are many types of detection techniques that were introduced for spatial multiplexing MIMO channels [7-11]. Vertical Bell Labs Space-Time Architecture/ Maximum A-Posteriori (V-BLAST/MAP) is a symbol detection algorithm for spatially multiplexed MIMO channels, which utilize the MAP rule in the detection process of the V-BLAST algorithm[9]. This leads to substantial performance enhancement; symbol error rates of the V-BLAST/MAP are close to the optimal and complex maximum likelihood (ML) scheme and in the same time have low-complexity close to the V-BLAST [9].

Low density parity codes (LDPC) [12] and Turbo Codes [13]are considered optimal in their bit error rate performance. Turbo coding using multiple convolutional coders and a random interleaver to counter or to minimize the effects of bulk error. Turbo Coding can operate close to the Shannon limit to prove itself as one of the most efficient codes which has a reasonable complexity [2, 14].

Recently, some of high potential research considers the case of using principle of iterative ("Turbo processing") in improving the performance of multiple antenna systems. One of the resulting classes of MIMO system referred to as Turbo-V-BLAST [15, 16]. Therefore, Turbo codes with independent fading coefficients at each coded bit in a codeword will get the best performance. In this paper, the symbol error rates of the V-BLAST algorithm with zero forcing (ZF), Minimum Mean Square Estimation (MMSE) detections are investigated. The performance of Turbo-V-BLAST algorithm with ZF, MMSE detections are also evaluated. The V-BLAST /MAP detection technique is used with Turbo coding. The Bit Error rate performance of this scheme is investigated using simulation in MATLAB software.

II V-BLAST/MAP DETECTION METHOD

The error performance and the decoding complexity of any spatial multiplexing MIMO should be always taken into consideration. The aim of this study is to design a structure that is powerful in terms of error performance and is practical to

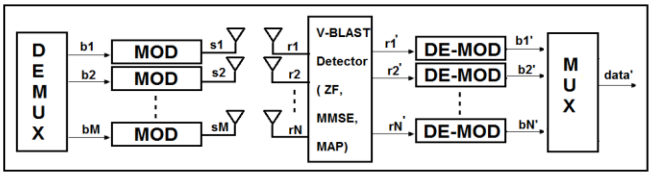

Figure 1 Uncoded V-BLAST system.

be implemented.

When MIMO system is used for multiplexing gain, maximum likelihood (ML) receiver suffers from a very high computational complexity [2].

Suboptimal receiver models are used to reduce the high decoding complexity in MIMO systems. Research in this area has focused on developing algorithms that has error performance close to the ML while being practical in the implementation purposes. The V-BLAST receiver is an example of

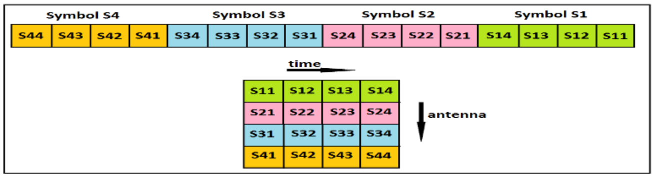

Figure 2Uncoded V-BLAST Vectors at Transmitter.

these suboptimal receivers which uses a layered architecture and applies successive cancellation by dividing the channel vertically[2].

The Maximum A Posteriori (MAP) rule is used in code detection to minimize the probability of errorP_e[15].
The MAP rule defined as,

$$\hat{a} = \arg_{a' \in A^M} \max\{\Pr(a' | r \text{ is received})\} \quad (1)$$

MAP rule offers optimal error performance, nevertheless it has exponential complexity order.
V-BLAST/MAP has combinations of V-BLAST and MAP rules. This algorithm has a layered structure similar V-BLAST, but uses a different technique inspired by the MAP rule in ordering the channel processing.
As a result of the combination, V-BLAST/MAP has higher complexity than the V-BLAST but with the substantial performance enhancement. Simulations show that V-BLAST/MAP has symbol error rates with marginal decline when compared to the optimal maximum likelihood (ML) scheme while having much lower complexity inherited from the V-BLAST [17].

III System Model

In this study, an $M \times N$ MIMO channel model has been considered. In each transmission interval, a vector $a = (a_1, a_2, \cdots, a_M)^T$of modulated signals is sent and a vector $r = (r_1, r_2, \cdots, r_N)^T$ is received. We assume an input-output relationship of the form,

$$\boldsymbol{r} = \boldsymbol{Ha} + \boldsymbol{v}, \quad (2)$$

where H is an $M \times N$ matrix represents the channel and is given by,

$$\boldsymbol{H} = \begin{bmatrix} \boldsymbol{h_{11}} & \cdots & \boldsymbol{h_{1M}} \\ \boldsymbol{h_{21}} & \cdots & \boldsymbol{h_{2M}} \\ \vdots & \ddots & \vdots \\ \boldsymbol{h_{N1}} & \cdots & \boldsymbol{h_{NM}} \end{bmatrix}, \quad (3)$$

where $\{h_{ij}\}$ is the complex channel gain between transmitter, j and receiver, i. Each entry of $\mathbf{H}$ is assumed to be independently identically distributed (i.i.d) zero mean complex Gaussian random variable with unity variance [18], and $v = (v_1, v, \cdots, v_N)^T$is the white Gaussian noise vector, we assume throughout the paper that the complex elements of v is a drawn from i.i.d. Gaussian distribution $v_i \sim CN(0,1)$. Perfect channel state information (CSI) is assumed only at the receiver side which can be practical for a relatively slowly time-varying channel [18].
The V-BLAST system is introduced in[19]. Figure 1 shows the transmitter and receiver of uncoded V-BLAST system with$M$ transmit and N receive antennas. The bit stream, b is demultiplexed into M sub-streams: $b_1, b_2, \cdots$, and b_M. These sub-streams are mapped to complex symbols $s_1, s_2, \cdots$, and s_M and transmitted from $TX_1, TX_2, \cdots$, and TX_M; respectively. The V-BLAST algorithm uses a layered structure. The layering is horizontal as all the symbols of a certain stream are transmitted through the same antenna. In the transmitter side, the streams are independently transmitted; the M transmitted streams are separated and then modulated separately with the modulators. In the receiver side, one of the V-BLAST detectors ZF, MMSE or V-BLAST/MAP is used [8].The input of the detector is the received vectors: $r_1, r_2, \cdots$, and r_N and the output is an estimation of transmitted symbols denoted by $s_1', s_2', \cdots$, and s_M'. The estimated symbol vector is demodulated and multiplexed to recover the transmitted data bits.
Figure 2 shows the V-BLAST process for a transmitterwith 4-

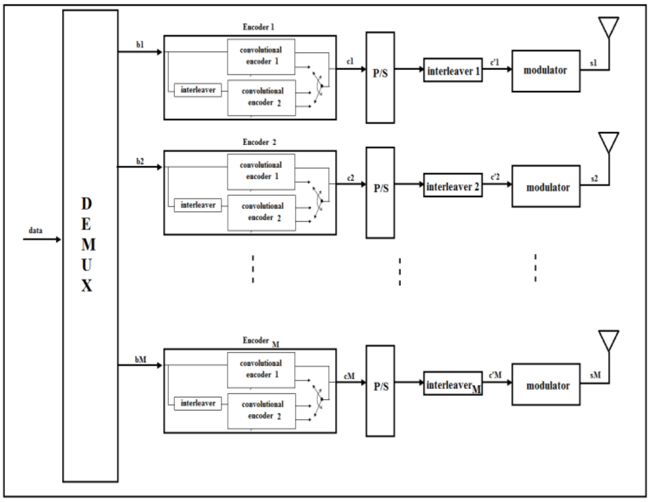

Figure 3 Coded V-BLAST Transmitter.

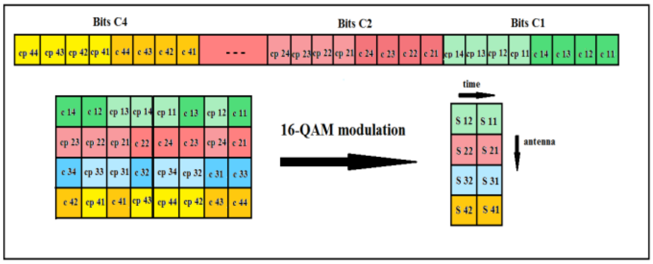

Figure 4 Codewords interleaving at the transmitter.

antennas. After demultiplexing and modulation of the bit stream, b, the symbol vectors are transmitted from the modulators: 1, 2, 3 and 4 which are denoted as $s_1, s_2, s_3$and s_4; respectively. s_1 can be expressed as $[s_{11}, s_{12}, s_{13}, s_{14}]$. Similarly,$s_2, s_3$and s_4 can be expressed as $[s_{21}, s_{22}, s_{23}, s_{24}]$,$[s_{31}, s_{32}, s_{33}, s_{34}]$, and $[s_{41}, s_{42}, s_{43}, s_{44}]$.

Figure 3 shows the basic block diagram of a coded V-BLAST transmitter with M transmit antennas. The bit stream b is demultiplexed into M sub-streams, $b_1, b_2, \cdots$, and b_M and each sub-stream is coded separately by ½ -rate Turbo code which consists of two convolutional encoders. Each sub-stream bits is encoded using he first encoder and the same bits are encoded using the

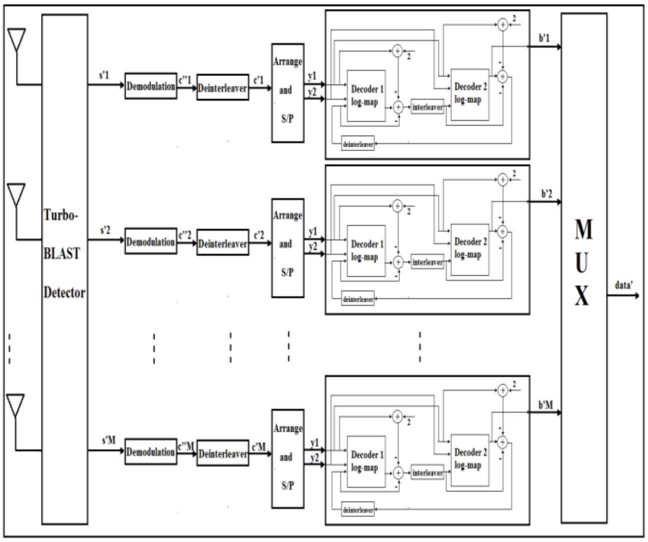

Figure 5 Coded V-BLAST Receiver.

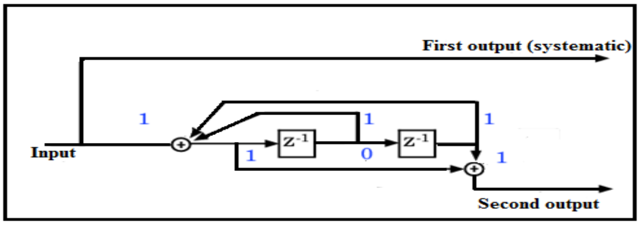

Figure 6 Illustration of how the generator polynomials is determined.

second encoder after they has been interleaved. The output of the Turbo encoder consists of the systematic bits, c_{ij} of the first encoder, and the parity bits, cp_{ij}. The parity bits are punctured using puncturing vector, based on the pattern P_p = [1,0] of the first encoder and the parity bits of the second encoder are punctured using puncturing vector, based on pattern P_p'=[0,1]. The $c_1, c_2, \cdots$, and $c_M$bits are interleaved using a pseudo-random interleaver. Then the interleaved bits, $c'_1, c'_2, \cdots$ and $c'_M$are mapped to complex symbols $s_1, s_2, \cdots$, and s_M using k-ary QAM modulation. Finally these symbols are transmitted from $TX_1, TX_2, \cdots$, and TX_M; respectively.

Figure 4 shows the code word interleaving at the transmitter.Figure 5 shows the basic block diagram of coded V-BLAST receiver with N receiving antennas. After receiving the vectors: $r_1, r_2, \cdots$, and r_N, estimation of transmitted symbols $s'_1, s'_2, \cdots$, and s'_M are calculated by one of detection types (ZF, MMSE, V-BLAST/ZF, V-BLAST/MMSE, V-BLAST/ZF/MAP or V-BLAST MMSE/MAP). After the demodulation, each output bits of $c'_1, c'_2, \cdots$ and $c'_M$are de-interleaved to compensate the interleaving at the coded V-BLAST transmitter. Then the output bits of each de-interleaver are arranged and separated to two-bit streams y_1 and y_2. The first stream bits are the systematic bits with parity bits for first encoder and second bit streams are the de-interleaved systematic bits. This is done to compensate the interleaving between the two encoders in Turbo code with parity bits for the second encoder. Now the bit streams are ready to be fed to the decoders. The detailed detection process can be found in [8].

IV Performance analysis

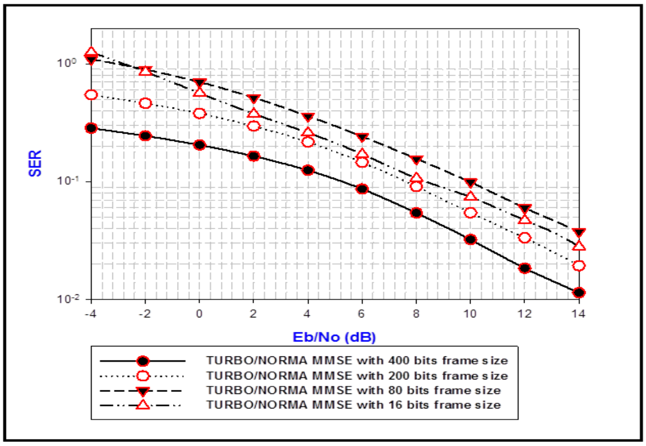

Figure 7 The SER performance for different frame size of Turbo/ normal MMSE.

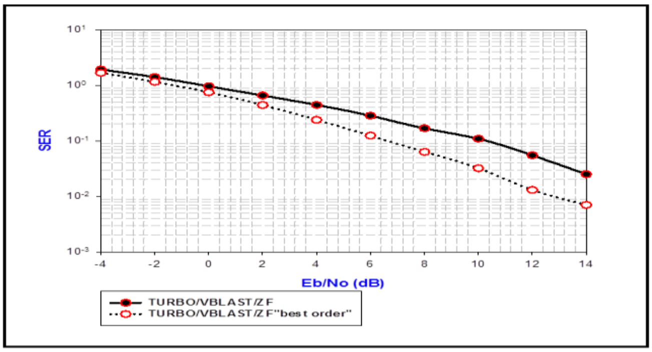

Figure 8 The SER performance for coded V-BLAST/ZF using Turbo code and coded V-BLAST/ZF using Turbo code with best order.

In this paper, all the simulations were done in MATLAB 2013 software using i7 processor and 4G MAM. The bit-error-rate performance of the system was simulated for different value of the signal-to-noise-ratio (SNR). The SNR is a figure of merit that is measured at the receiver side. The schemes under investigation are the BLAST scheme (uncoded V-BLAST and coded V-BLAST using Turbo code). While, the detection strategies used in this paper are zero-forcing, MMSE, V-BLAST/ ZF, V-BLAST/MMSE, V-BLAST/ZF/MAP, V-BLAST/MMSE/MAP,V-BLAST/ZF/ ordering and V-BLAST/MMSE/ordering. We have also considered in our simulation different frame lengths for Turbo decoder. The channel encoder is 1/2 rate Turbo encoder which has two puncturing 4-state convolutional encoders. The convolutional encoder is punctured with pattern in the Table 1 and with generators polynomial (7, 5) octal, see Figure 6. Table 2 shows a 1/2 rate convolution code used in this paper. The type of channel decoder is LOG-MAP-decoder and type of modulation is 16-QAM.

The channel is Rayleigh fading with Additive White Gaussian noise (AWGN). For each frame, a new random realization of the channel matrix, $\boldsymbol{H}$, is used. Number of frames is assumed to be 10000 and each frame has 16 bits. A frame is considered to be received incorrectly if any single bit of the frame is wrongly decoded.

Figure 7 shows comparison of the symbol error rate performance for different frame size of Turbo/ normal MMSE without interference nulling and interference cancellation. It can

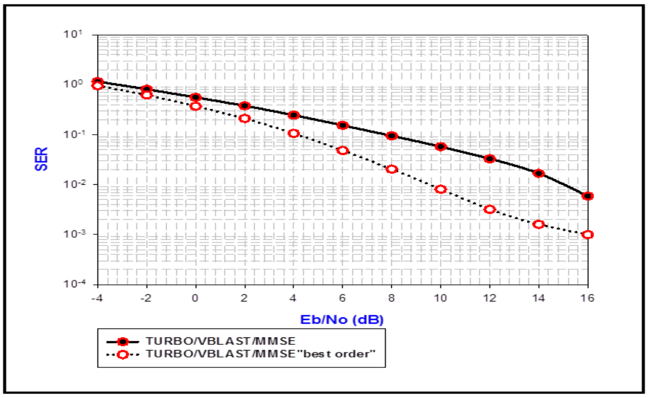

Figure 9 The SER performance for coded V-BLAST/MMSE using Turbo code and coded V-BLAST/MMSE using Turbo code with best order.

be seen that the larger the frame size, the better is the SER performance.

Figure 8 and Figure 9 show comparison of the symbol error rate performance for coded V-BLAST using Turbo code without ordering and with best order architectures using 4×4 MIMO system and 16-QAM modulation. The detection is

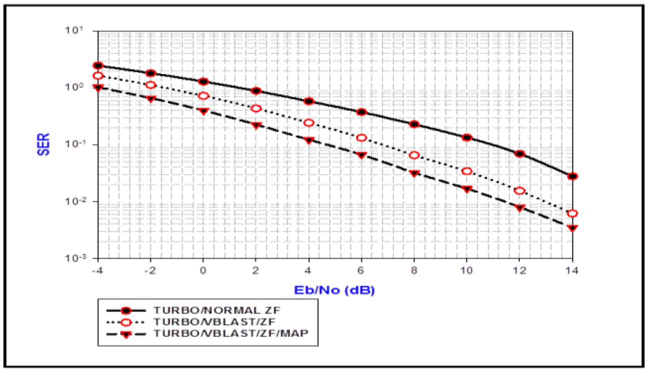

Figure 10 The SER performance for coding normal ZF, V-BLAST/ZF and V-BLAST/ZF/MAP using Turbo coding.

done by ZF and MMSE techniques.

From Figure 8 and Figure 9, we can see that the performance of Turbo/V-BLAST/ZF with best order architecture is better than Turbo/V-BLAST/ZF without order architecture. For example, in case of SER = 10^{-1}, we have a coding gain of 3.3 dB for the ordered coded system compared to the system without symbol ordering.

Whereas the gain in case of symbol ordering for Turbo code with MMSE detection technique is 5.3 dB at symbol error rate of 10^{-2}.

Figure 10 shows comparison of the symbol error rate performance for Turbo/normal ZF without Interference nulling and Interference cancellation, Turbo/V-BLAST/ZF and proposed Turbo/V-BLAST/ZF/MAP techniques with 4×4 antennas and 16-QAM modulation.

It can be seen from figure 10 that the performance of Turbo/V-BLAST/ZF/MAP technique is the best among the three techniques. The performance of Turbo/V-BLAST/ZF is better than Turbo/normal ZF without Interference nulling and Interference cancellation. For example in case of SER = 10^{-1}, we have a coding gain of 4 dB for the Turbo/V-BLAST/ZF system compared to the Turbo/normal ZF system. Whereas the gain in case of Turbo/V-BLAST/ZF/MAP system is 1.6 dB compared to the Turbo/V-BLAST/ZF system at symbol error rate of 10^{-2}.

Figure 11 shows comparison of the symbol error rate performance for Turbo/normal MMSE without interference nulling and interference cancellation, Turbo/V-BLAST/MMSE and proposed Turbo/V-BLAST/MMSE/MAP techniques with 4×4 antennas and 16-QAM modulation.

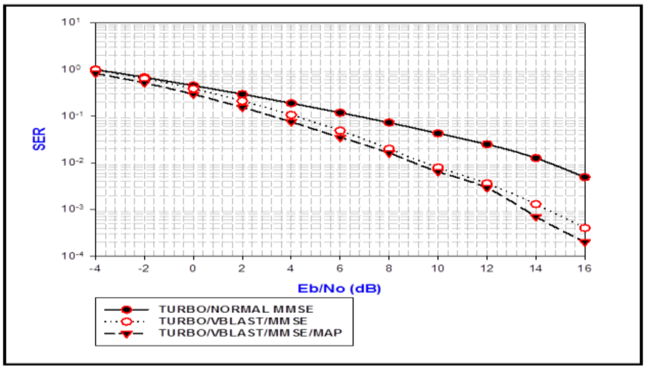

Figure 11 The SER performance for coded normal MMSE, V-BLAST/MMSE and V-BLAST/MMSE/MAP using Turbo coding.

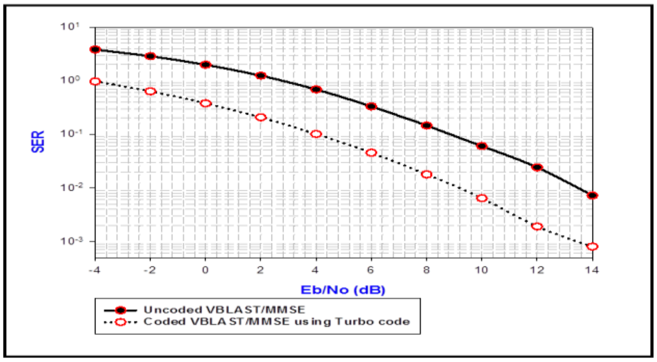

Figure 12 The SER performance for uncoded V-BLAST/MMSE and coded V-BLAST/MMSE using Turbo code.

From Figure 11, we can see that the performance of Turbo/V-BLAST/MMSE/MAP technique is best among the three techniques. The performance of Turbo/V-BLAST/MMSE is better than Turbo/normal MMSE without Interference nulling and Interference cancellation. For example in case of SER = 10^{-2}, we have coding gain of 5 dB for the Turbo/V-BLAST/MMSE system compared to the Turbo/normal MMSE system. Whereas the gain in case of Turbo/V-BLAST/MMSE/MAP system is 1 dB compared to the

TABLE 1
Puncturing Pattern

Puncturing patterns	
Systematic output of the first encoder	[1 1]
Parity output of the first encoder	[1 0]
Parity output of the second encoder	[0 1]

Turbo/V-BLAST/MMSE system at symbol error rate of 10^{-3}.

Figure 12 shows comparison of the symbol error rate performance for VBLAST/MMSE without coding and V-BLAST/MMSE with using Turbo code techniques with 4×4 antennas and 16-QAM modulation.

From Figure 12, we can see that the performance of coded V-BLAST/MMSE technique is better than uncoded V-BLAST/MMSE. For example in case of SER = 10^{-2}, we have coding gain of 4.3 dB for the system with Turbo code compared to un-coded VBLAST/MMSE system.

V CONCLUSION

This paper has addressed a number of important issues associated with Turbo coded MIMO detection techniques. In particular, provided a detailed description, analysis and comparison of SER performance of several detection techniques and gave a recommendation for those promising techniques that are potentially amenable to hardware implementation. In this paper, a successful implementation of a system design of “Turbo/VBLAST/MAP”, which combines Turbo code with the detection technique VBLAST/MAP is presented.

TABLE 2
The parameters of a ½ rate convolutional code

Memory size	Generator polynomial in octal	Generator polynomial in binary
2	[7, 5]	[111, 101]

The Turbo/V-BLAST system was also presented with different detection techniques. Comparison between these schemes was made to observe that the MMSE algorithm performs slightly better than ZF algorithm. The same stands in case of using V-BLAST/MMSE is perform better than V-BLAST/ZF. V-BLAST/MMSE/MAP performs better than V-BLAST/ZF /MAP.

Using V-BLAST/MAP with either ZF or MMSE improves the performance of the system significantly.

The main conclusion of this paper that Turbo coded V-BLAST/MAP offers significantly better SER performance than others V-BLAST detection techniques at a modest increase in complexity.

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Alaa H. Al Habbash was born in Riyadh, Saudi Arabia, in 1985. He received the B.Sc. degree and the M.Sc. degree in Telecommunication Engineering from Islamic University Gaza, Palesine in 2008 and 2013, respectively. He is currently a Communication Engineer at Ministry of Communication and Information Technology in Gaza, Palestine. His current research interests are Space Time Coding, Turbo Codes, and Spatial Modulation.

Ammar M. Abu-Hudrouss was born in Khan-Younis, Palestine, in 1977. He received the B.Sc. degree from Islamic University Gaza, Palestine, in 1995. He received the M.Sc. degree in Telecommunication Engineering and the Ph.D. degree in Communication Engineering from Birmingham University, Birmingham, U.K., in 2003 and 2007, respectively. He was a visiting researcher at University of York from 9/2012 to 9/2013. The research visit was funded by Arab Fund for Social and Economic Development as a part of Distinguished Scholar Award. He is currently an Associate Professor at Islamic University of Gaza, Palestine. His current research interests are Spatial Modulation, Space Time Coding, Turbo Codes, and Low Density Parity Codes.