Design of the wireless communication system of a rescue robot

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Abstract

During last few years the the development of the technology in the domain of computer science, communication and signal processing was a key enabling factor resulting in the widespread (penetration, use, ubiquitous use/application) of wireless data communication systems. To enlarge the data rate and/or its robustness to the additive noise of the wireless channel, the modern communication systems use some effective data coding, namely the Space-time coding which benefits form the space time diversity of the Multiple Input Multiple Output channel, become very popular.

In our project, we develop a proprietary communication system operating in ISM band (2.4GHz) for transmission of video-sensoric data of a rescue robot. The system should transmit video data from one or two cameras and data from few other sensors. The video-sensoric data are then treated and visualized at the operator base station. Depending on the channel capacity, the system will send the high quality data for stereo-vision or the compress data from one cameras. Thus the different communication schema should be used in different cases.

In the paper, we preset the simulation results of the tree different ST codes: V-BLAST, D-BLAST OFDM for the spatial multiplexing and Alamouti OFDM – all under the perfect channel knowledge conditions. Finally, the overall scheme of the communication system and its adaptability to the channel conditions are discussed.

1 Introduction

During last few years the the development of the technology in the domain of computer science, communication and signal processing was a key enabling factor resulting in the widespread (penetration, use, ubiquity use/application) of wireless data communication systems. As the example of the successful technologies we may mentioned Blue-Tooth and IEEE 802.11 (WiFi) wireless LAN (WLAN). Recently, more and more broadband communication standards use OFDM type of modulation (DVB-T, DVR, IEEE 802.16, WiMax etc.). The reason is, that OFDM effectively use the wide frequency band and the relative simplicity receiver design.

To enlarge the data rate and/or its robustness to the additive noise of the wireless channel, in modern communication systems some effective data coding is used. Namely the Space-time coding which benefits form the space time diversity of the Multiple Input Multiple Output (MIMO) channel, become very popular.

In our project, we develop a proprietary communication system operating in ISM band (2.4GHz) for transmission of video-sensoric data of a rescue robot. The system should transmit video data from one or two cameras (two cameras for stereo-vision) and data from different sensors (such as 3D laser scanner). The video-sensoric data are then treated and visualized at the operator base station. Depending on the channel capacity, the system will send the high quality data for stereo-vision or the compress data from one cameras. Thus the different communication schema should be used in different cases.

In the paper, we preset the simulation results of the tree different ST codes: V-BLAST, D-BLAST OFDM for the spatial multiplexing and Alamouti OFDM – all under the perfect channel knowledge conditions. Finally, the overall scheme of the communication system and its adaptability to the channel conditions are discussed.

The paper is organized as follows: in the second section we present the system settings. Section tree presents successively tested method of space time coding i.e. D-BLAST, V-BLAST and Alamouti OFDM coding. Section 4 presents the simulation results. Section 5 discuss the system adaptability and conclude the work.

2 System settings

We assume that the communication system is described as follows: symbols to be transmitted are first digitally modulated and sent to the receiver through the communication channel. We suppose to use multiple antenna at the both sides, at the transmitter and receiver. Each couple of transmit and received antenna constitutes one communication channel. We assume the channel impulse response to be finite in duration (FIR) and real-valued. The channel impulse response $h(z)$ is assumed to be a priory unknown at the transmitter, causal and bounded-input bounded-output (BIBO) stable. Gaussian (white) noise $w(t)$ is added to the channel output. In that case, the input of the receiver is a N_{rx} dimensional observation vector $\mathbf{r}_n$. The MIMO channel model has the form of the form:

$$\mathbf{r}_n = \sum_{i=0}^{N_{tx}} \mathbf{H}_{(i)} \mathbf{s}_n^{(i)} = \mathbf{H}_A \mathbf{s}^A \tag{1}$$

where $\mathbf{s}_n$ is the symbol source vector send from transmit antenna i, $\mathbf{w}_n$ is the noise column vector of size N_{rx}, $\mathbf{H}$ is a $N_{rx} \times N_h$ matrix representing the channel impulse response, N_{tx} and N_{rx} is the number of transmit and received antennas and N_h is the channel length.

Depending on the communication system, the $i - th$ antenna can be used for data transmission of : i) data transmit ion of $i - th$ user in multiuser environment ii) spatial multiplexing of one high speed data stream or iii) space time diversity coding of one data stream to obtain lower bit error rate. In the following section, we describe the basic methods for data multiplexing (V-BLAST and D-BLAST algorithms) and Space-Time coding (Alamouti coder/decoder).

3 Space time coding

Current transmission schemes over MIMO channels fall into two basic categories: data rate maximization or diversity maximization. The first one focuses on improving the overall capacity. In the second scheme one tries to encode the individual streams to protect transmission against the errors caused by channel fading and noise plus interference.

In our system we use both schemes. In dependence of channel capacity we transmit streams from two cameras to be able to use stereo-vision, elsewhere in the poor channel conditions, only one camera will be used with lower resolution. In the first case, the V-BLAST or D-BLAST decoder with Reed-Solomon coding will be used. In the second, the Alamouti block coding will be applied.

3.1 V-Blast and D-Blast coding scheme

Two layered space-time architectures V-BLAST (Vertical Bell Labs space-time architecture) and D-BLAST (Diagonal BLAST) were proposed in [2] and [3]. The BLAST technique is essentially a decision feedback space-time multiuser detector.

In the coded V-BLAST, the data are first demultiplexed into N_{tx} data streams, each of which is independently encoded, interleaved and symbol mapped. At the receiver, the MMSE criterion is used to decouple the sub-streams. The receiver first demodulates one of the sub-streams by nulling out the others with a decorrelator. After this sub-stream is decoded, its contribution is subtracted from the received signal and the second sub-stream is demodulated by nulling out the remaining interference.

We observe that in the above version of V-BLAST, the first stage (detecting the first sub-stream) is the bottleneck stage. There are various ways to improve the performance of V-BLAST, by improving the reliability at the early stages.

Clearly, the order in which the sub-streams are demodulated affects the performance. In [2], it is shown that fixing the same date rate for each sub-stream, the optimal ordering is to choose the sub-stream in each stage such that the SNR at the output of the corresponding decorrelator is maximized. Simulation results in [2] show that a significant gain can be obtained by applying this ordering.

Diagonal BLAST (D-BLAST) is a simple extension of the V-BLAST architecture, with coding of the input data stream over the signals transmitted on different antennas. This extension promises a higher diversity gain over V-BLAST.

In D-BLAST, the input data stream is divided into sub-streams, each of which is transmitted on different antennas time slots in a diagonal fashion. For example, in a system, the transmitted signal in matrix form is

$$\begin{bmatrix} 0 & x_1^{(1)} & x_1^{(2)} & \cdots \\ x_2^{(1)} & x_2^{(2)} & x_2^{(3)} & \cdots \end{bmatrix}$$

where x_i^k denotes the symbols transmitted on the ith antenna for sub-stream k. The receiver also uses a successive nulling and canceling process. In the above example, the receiver first estimates $x_2^{(1)}$ and then estimates $x_1^{(1)}$ by treating $x_2^{(2)}$ as interference and nulling it out using a decorrelator. The estimates of $x_1^{(1)}$ and $x_2^{(2)}$ are then fed to a joint decoder to decode the first sub-stream. After decoding the first sub-stream, the receiver cancels the contribution of this sub-stream from the received signals and starts to decode the next sub-stream, etc. Here, an overhead is required to start the detection process; corresponding to the symbol in the above example.

3.2 Alamouti space-time block coding scheme

Alamouti space-time coding is block ST coding scheme originally proposed by Alamouti using two transmit antennas [1] and generalized in [5] for an arbitrary number of transmit antennas and is able to achieve the full diversity promised by the transmit and receive antennas. These codes retain the property of having a very simple maximum likelihood decoding algorithm based only on linear processing at the receiver.

A spacetime block code is defined by a $p \times N_{tx}$ transmission matrix $\mathcal{G}$. The entries of the matrix $\mathcal{G}$ are linear combinations of the variables (data symbols) $x_1, x_2, \ldots, x_k$ and their conjugates. For example, the transmition matrix originally proposed by Alamouti is defined by

$$\mathcal{G}_2 = \begin{pmatrix} x_1 & x_2 \\ -x_2^* & x_1^* \end{pmatrix}$$

Maximum likelihood decoding of any spacetime block code can be achieved using only linear processing at the receiver and is dependent on the transmittion matrix structure and number of received antennas. In our example of $\mathcal{G}_2$ with two transmit and one receive antennas, the estimetes produced by the decoder are of the following form:

$$\bar{x}_0 = h_0^* r_0 + h_1 r_1^* \quad (2)$$
$$\bar{x}_1 = -h_0 r_1^* - h_1^* r_0 \quad (3)$$
$$(4)$$

where h_0 and h_1 are flat fading channel coefitients between transmit antenna one and two rep. and receive antenna and r_1 and r_2 are signals received in time t and $t+1$ resp. For details see [4].

4 Simulation results

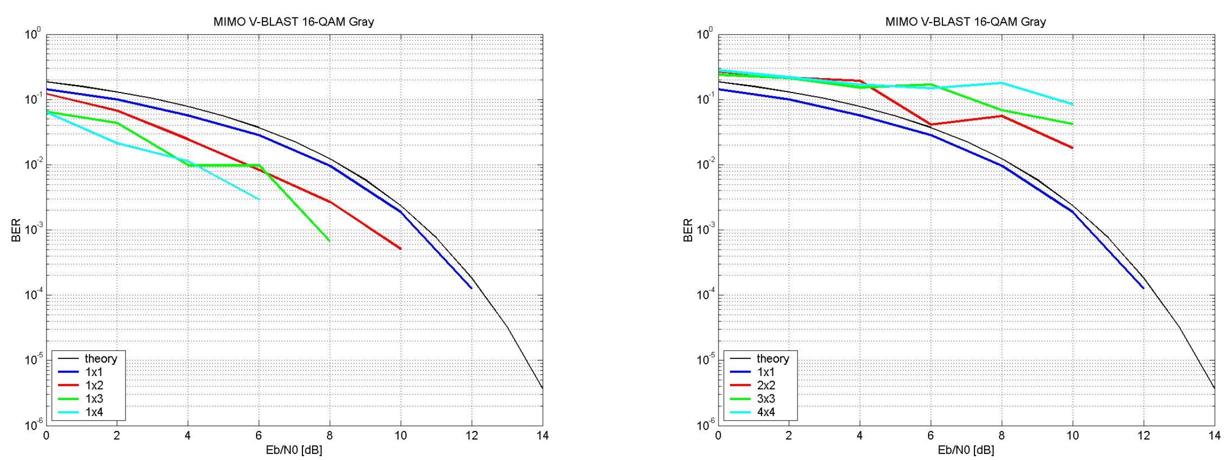
For the system test purposes and as a golden model of the final implementation of the communication system, we have implemented three mentioned methods in Matlab. The OFDM modulation is used on each antenna stream to convert frequency selective fading wideband channel to a set of narrow band flat fading channels.

All the test shares the following considerations:

- perfect time and frequency synchronization at the receiver
- channel state is constant during a frame of size 1000 symbols
- we run 100 independent test for each SNR
- data symbols are 16-QAM modulated
- no forward error correction is used

The results for the V-BLAST system are presented in figures

1. From the first figure, we may see how the number of receiver antennas improves the system performance. On the other hand, adding the more transmit antennas degrades the BER. This is a natural behavior since BLAST technique, independent data streams are send through antennas and this produce more interference to be mitigated by the nulling algorithm.



a) b)

Figure 1: V-BLAST: a) Influence of the number of receiver antennas to a BER(SNR) function b) BER as a function of SNR for V-BLAST system with equal number of transmit and receive antenna

The simulation results for the D-BLAST are presented in figure D-BLAST. In that case the Reed-Solomon coding was used. The size of the RS coded data block corresponds to the size of the block in D-BLAST layer. This significantly improve the quality of the decision-feedback detector. In the example, systems with equal number of transmit and receive antennas are presented.

Considering the performance of the D-BLAST system, it is possible to see certain improvements compared to the V-BLAST.

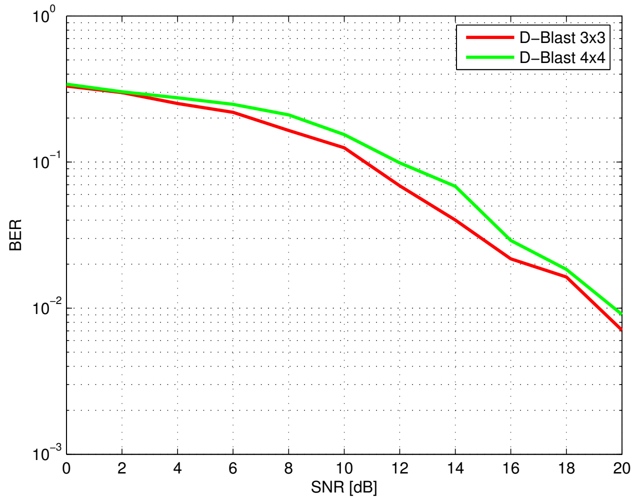
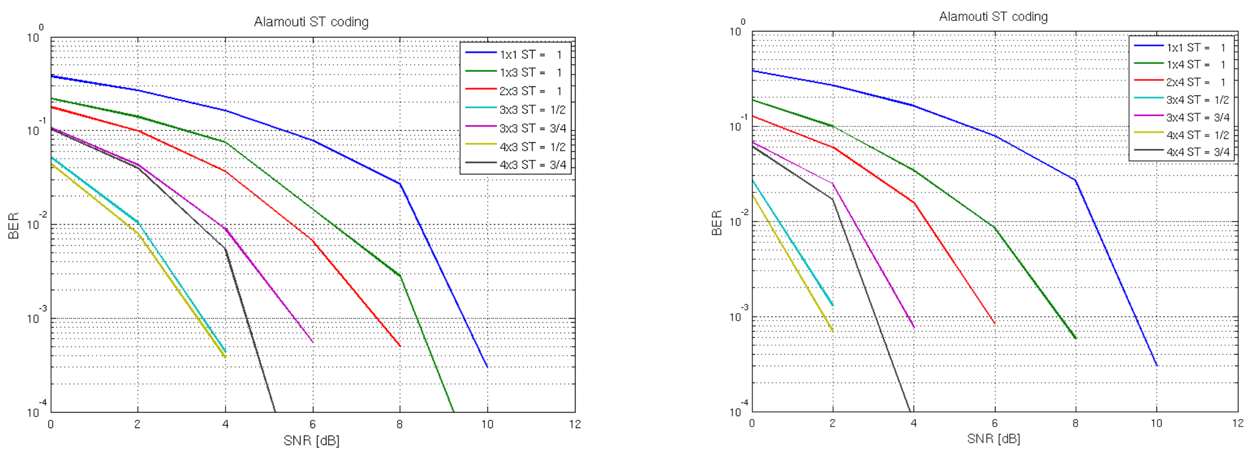


Figure 2: D-BLAST: BER as a function of SNR for D-BLAST system with equal number of transmit and receive antenna

Finally, Figures **??** and **??** show the performance results of the Alamouti block ST coding. Contrary to the BLAST system, ST coding minimize the BER as the number of antennas (transmit or receive) grows. In these examples, the performance of different coding rates (i.e. different number of transmit antennas) for three (Figure **??** a)) and four (Figure **??** b)) receive antennas are shown.



a) b)

Figure 3: Alamouti STC: Performance of the system with for 3 received antennas. Different coding rates are tested (no. of transmit antennas varies from 2 to 4)

5 Conclusion

In the paper we have presented the tree Multiple Input/Multiple Output communication schemes. These algorithms are planned to be used for an adaptive communication system for the transmission of the video-sensoric data of a rescue robot. For the cases of good channel condition, the higher amount of the information data will be send (to enable stereo-vision at the operator station). Contrary, in the case of the poor channel state, the robust Alamouti coding will take the place (only one video source will be transmitted).

The overall system is planned to be implemented using the software define radio technology. These days, parts of the system has been coded in programmable hardware (FPGA) such as convolution and RS coders and decoders, OFDM (de)modulator, synchronization and Alamouti (de)coders.

Regarding the presented test, we have decided to fix the number of transmit antennas to 3 and receive antennas up to 4. For the purpose we have developed a HW platform to test the system in a real environment.

References

[1] S. M. Alamouti. A Simple Transmit Diversity Technique for Wireless Communications. *IEEE J. Selected Areas Commun.*, 16(8):1451–1458, 10 1998.

[2] G. J. Foschini. Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas . *Bell Labs Tech. J.*, 2(2):41–59, 1996.

[3] G. J. Foschini, G. D. Golden, R. A. Valenzuela, and P. W. Wolniansky. Simplified processing for high spectral efficiency wireless communication employing multi-element arrays. *IEEE J. Selected Areas Commun.*, 17:1841–1852, 11 1999.

[4] V. Tarokh, H. Jafarkhani, and A. R. Calderbank. Space-Time Block Coding for Wireless Communication: Performance Results. *IEEE J. Selected Areas Commun.*, 17(3):451–460, 3 1999.

[5] V. Tarokh, H. Jafarkhani, and A. R. Calderbank. Spacetime block codes from orthogonal designs. *IEEE Trans. Inform. Theory*, 45(5):1456–1467, 6 1999.

Acknowledgement: The work has been supported by the grant no. 1ET100750408 of the Grant Agency of the Czech Academy of Sciences.

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