MIMO-OFDM System's Performance Using LDPC Codes for a Mobile Robot

Omar Daoud[1] and Omar Alani[2]

[1] Omar Daoud, Communications and Electronics Engineering Department, P.O. Box 1, 19392 Amman, Jordan
odaoud@philadelphia.edu.jo
[2] Omar Alani, School of Electronic and Electrical Engineering, University of Leeds Woodhouse Lane, Leeds, LS2 9JT, UK
o.y.k.alani@leeds.ac.uk

Abstract. This work deals with the performance of a Sniffer Mobile Robot (SNFRbot)-based spatial multiplexed wireless Orthogonal Frequency Division Multiplexing (OFDM) transmission technology. The use of Multi-Input Multi-Output (MIMO)-OFDM technology increases the wireless transmission rate without increasing transmission power or bandwidth. A generic multilayer architecture of the SNFRbot is proposed with low power and low cost. Some experimental results are presented and show the efficiency of sniffing deadly gazes, sensing high temperatures and sending live videos of the monitored situation. Moreover, simulation results show the achieved performance by tackling the Peak-to-Average Power Ratio (PAPR) problem of the used technology using Low Density Parity Check (LDPC) codes; and the effect of combating the PAPR on the bit error rate (BER) and the signal to noise ratio (SNR) over a Doppler spread channel.

Keywords: Low Density Parity Check (LDPC) codes, MIMO, and OFDM.

1 Introduction

Due to the rapid growth of wireless communication service, ubiquitous robotics becomes an interesting area for researchers. Although it takes several forms, this kind of robots requires a specific combination of wireless communication, user interface and signal processing techniques to assist humans in everyday tasks. Sniffer Mobile Robot (SNFRbot) is a special kind of robots, which supplies the administrator with fully monitoring capability of a dangerous environment. This monitoring is accomplished by sending live videos through Multi-Input Multi-Output - Orthogonal Frequency Division Multiplexing (MIMO-OFDM) modems to the administrator. If there are no actions taken by the administrator, the SNFRbot will act as a sub-administrator and trying to solve the situation temporarily.

Wireless link that employs multiple antennas at both ends has recently been shown to have the probability of achieving extraordinary data rates. This could be achieved in a rich scattering environment [1]. The corresponding technology is known as spatial multiplexing or BLAST and allows an increase in bit rate in a wireless radio link

R. Mehmood et al. (Eds.): EuropeComm 2009, LNICST 16, pp. 83–90, 2009.

without additional power or bandwidth consumption [2], [3]. In a time-varying frequency-selective fading channel, the BLAST system may suffer from severe performance degradation. To avoid performance loss, OFDM may be exploited to eliminate the inter-symbol interference (ISI) [4]. It has been shown [5], however, that OFDM suffers from high sensitivity to non-linear distortion caused by components in the transmitter part, such as Digital to Analogue Converters (DAC), mixers and High Power Amplifiers (HPA). Thus, the output signal will suffer from intermodulation distortion resulting in energy being generated at frequencies outside the allocated bandwidth. Daoud *et. al.* [6], [7] introduced a novel technique to improve the OFDM systems' efficiency by alleviating the PAPR problem based on linear coding techniques.

This paper presents improving the proposed SNFRbot-based coded MIMO-OFDM system by combating the PAPR problem and its effect on the BER and SNR. A detailed description of the SNFRbot architecture is given in Section 2. To confirm the effectiveness of the proposed technique, computer simulation results are given in Section 3, followed by conclusion in Section 4.

2 SNFRbot Architecture

Fig. 1 shows the generic architecture of SNFRbot. Generally, it consists of four layers; the sensor/video layer, software/hardware (SW/HW) layer, the wireless layer and the administrator layer.

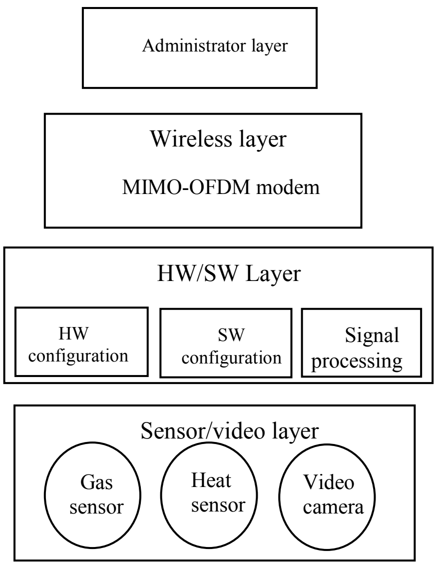

Fig. 1. Generic structure of SNFRbot

In the sensor/video layer, the SNFRbot monitors the environment's safety. If any sudden accident happens that causes a highly deadly gases concentration or a high temperature around, the video cam mode will be activated to send live video to the administrator. The second layer is HW/SW layer. In this layer, both of the SNFRbot hardware and software are reconfigurable to satisfy the environment conditions, such as the SNFRbot speed. The thirds layer allows the SNFRbot to send the live videos through a coded MIMO-OFDM modem. This modem consists of four parts; Fig.2 shows the transmitter block diagram while the receiver will be as the inverse stages of the ones that are shown in Fig.2.

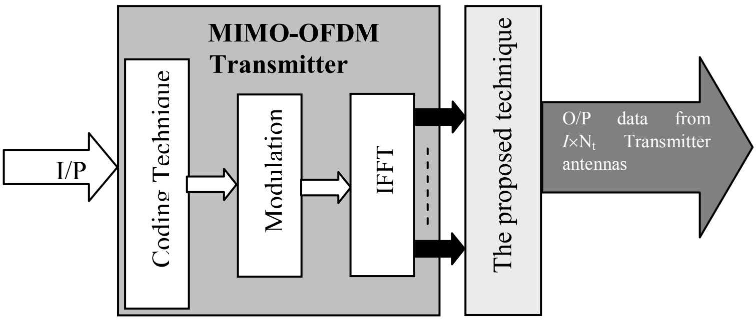

Fig. 2. Block diagram of the coded MIMO-OFDM transmitter

From Fig.2, the MIMO-OFDM transmitter consists of coding technique stage, modulation stage, the Inverse Fast Fourier Transform (IFFT) stage and the proposed stage to combat the PAPR problem. The proposed stage is summarized in the flow-chart that is shown in Fig. 3. Finally, the administrator layer, mainly it is the layer that will take actions according the received videos through the MIMO-OFDM modem.

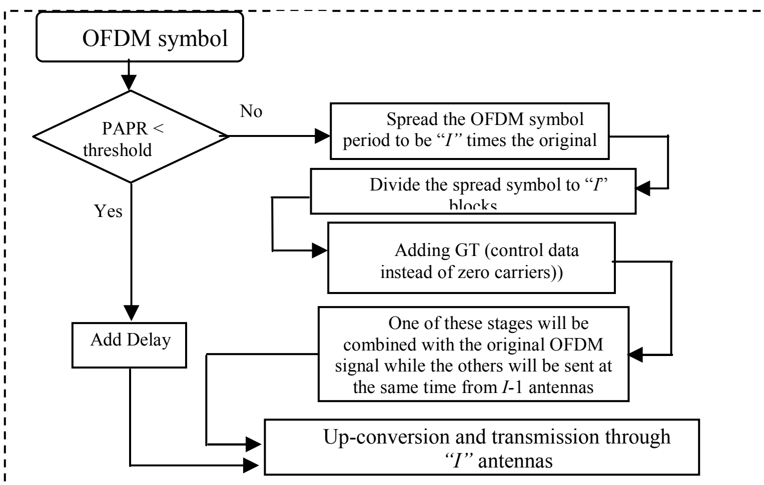

Fig. 3. The flowchart of the previously proposed work in [6] to combat the PAPR

The SNFRbot prototype is approximately in the size of 6×10^{-3} m^3 as shown in Fig.4. At this stage, it has the following parts; motor drive, a designed MIMO-OFDM modem using field-programmable gate array (FPGA), microcontroller, power supply, sensors and a video cam.

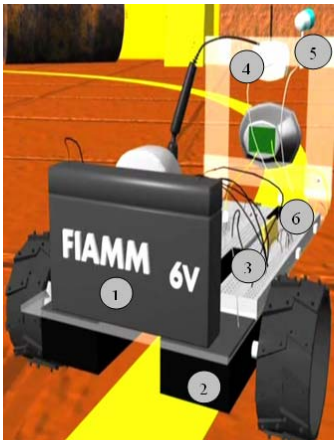

Fig. 4. The prototype of SNFRbot: 1) 6V battery, 2) motor driver, 3) microcontroller, 4) video cam, 5) heat sensor, and 6) gas sensor

In this work, the coded MIMO-OFDM modem has been built in accordance to the IEE802.11 g/n specifications to test the wireless communication of SNFRbot. It was decided to implement the algorithm in FPGA available from Xilinx [8]. The algorithm was decomposed into its functional blocks and these blocks implemented using Verilog, a well known hardware description language (HDL). 'ISE' [9], a development environment provided by Xilinx, incorporates a Verilog synthesis toolchain allowing the high-level description to be compiled and optimized. Elements of this toolchain allow the generation of a bitstream file from which the FPGA devices can be directly programmed. Furthermore, the ISE environment also provides a behavioural simulator that allows the performance of the design to be examined post-synthesis, i.e. complete with all of the routing delays and imperfections that would be present in the physical instantiation of the design in an actual FPGA. This proved to be an extremely useful tool during the implementation of this technique.

The blocks described in Fig.2 were successively implemented in Verilog HDL, each being tested and evaluated using the behavioural simulator before the next block in the chain was implemented. Additional blocks were also implemented to provide the necessary timing, synchronization and handshake signals necessary to ensure correct data transport between each block.

During the compilation and synthesis process, the ISE toolchain generates a report showing device utilisation. Once the system was implemented in Verilog HDL this report was used to determine the overall size and structure of the FPGA device required to implement this technique.

The full implementation was found to fit comfortably in a Xilinx XC2S150 part, one of the Spartan 2E series. The utilisation report indicated that approximately 75%

of the device was used. The Spartan 2E series is a mature, readily available low cost family, showing clearly that the technique can be implemented using low-cost hardware.

It is possible to reduce device utilisation still further. In the implementation used during this research, the IFFT block was implemented directly from the flow-graph to expedite development. If necessary, better, space-efficient FPGA implementations of the FFT and IFFT are available and could be used.

3 Hardware and Simulation Results

In order to verify the mathematically derived result, a MATLAB simulation program was performed and verified using a signal generator and spectrum analyser. The verification process is based on the Agilent Signal Studio Toolkit. The system parameters were:

- A uniformly distributed randomly generated data sequence was generated.
- Channel coding rate is 1/3.
- Different modulation techniques (QPSK, and 64QAM).
- IFFT size of 4k.
- Spreading rate equals to 3.
- Two different channel types; flat fading and Doppler spread channels.

For the hardware implementation and during the testing, 350 OFDM symbols were used to check the efficiency of the proposed technique. These data has been used as an input data to the proposed work block in Fig. 2. The average of the PAPR reduction ratio between the conventional and processed OFDM symbols is used in drawing the CCDF plots.

Fig. 3 shows the CCDF plots for the real part of the OFDM symbols. In this section, the model is limited to 64QAM modulation technique, coding rate equals 1/3 and a spreading rate equal to 3 for simplicity purpose. This figure is divided into three parts of CCDF plots from the designed MIMO-OFDM blocks with the proposed work, which combats the PAPR. Then the system's data rate will be improved. The first plot shows the system's efficiency without coding techniques, while the second one shows combating the PAPR using the proposed technique based turbo coding technique, and the last one shows the achieved improvement of reducing the PAPR based LDPC codes.

Fig. 4 shows the BER vs. the SNR of the QPSK modulated data, while Fig.5 shows the result of the 64QAM modulated data. Both of figures check the efficiency of the LDPC coded data in both Doppler spread and flat fading channels.

From Fig.4, the flat fading channel results give better system performance than the Doppler channel. As an example, at 6 dB SNR the BER was 3.5×10^{-2} for the flat fading channel while it was 6×10^{-1} at the same threshold for Doppler channel.

These results have been improved by changing the modulation technique to be 64 QAM. The improvement will be shown in Fig.5. From Fig.5, at the same value that has been taken previously; 6dB SNR, the BER has been improved in the flat fading situation from 3.5×10^{-2} previously to be 8.2×10^{-4}. For the Doppler channel there is also improvement. This value has been improved from 6×10^{-1} to be 1.8×10^{-1}. Thus, changing the modulation technique for the LDPC coded MIMO-OFDM system improves the system's performance.

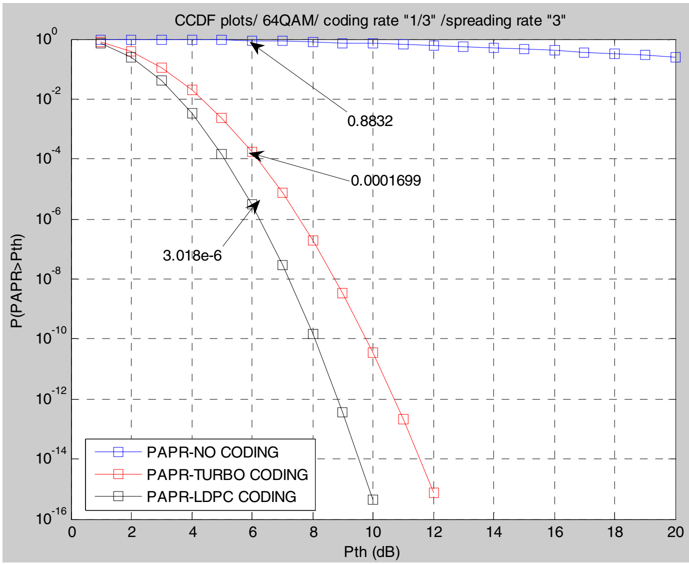

Fig. 5. The CCDF plots for the coded MIMO-OFDM hardware designs

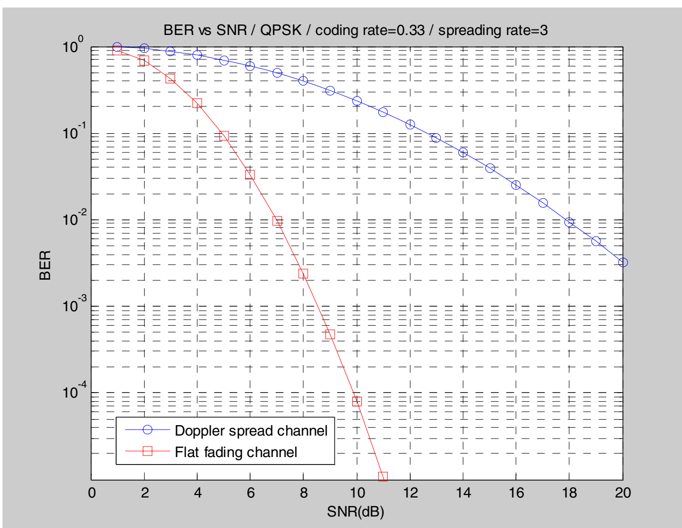

Fig. 6. The BER vs. SNR plots for the LDPC coded MIMO-OFDM simulation-based QPSK modulation technique

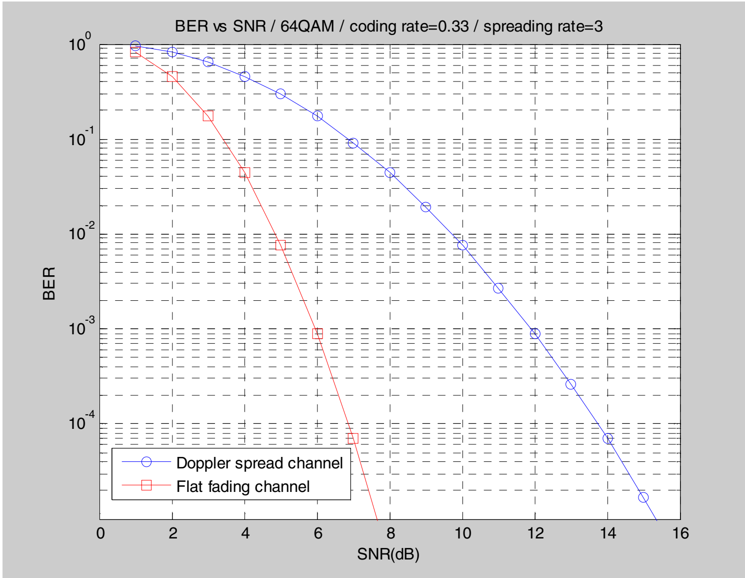

Fig. 5. The BER vs. SNR plots for the LDPC coded MIMO-OFDM simulation-based 64QAM modulation technique

4 Conclusion

The objective of this work is improving the data rate of the proposed SNFRbot robot, which can send live data to the administrator. This is fulfilled by imposing a combination between two powerful techniques; MIMO and OFDM to the wireless layer as it is shown in Fig.1. Moreover, the coded MIMO-OFDM systems performance has been improved by combating one of the OFDM drawback; PAPR. Then, the SNFRbot takes the advantage from this combination to send better resolution live videos based on one of the thirds generation (3G) mobile communication systems propositions.

From the hardware design of the previously published proposed technique, it can be concluded that it's feasible, practical and cost-effective in a real time application.

References

1. Naguib, A.F., Seshadri, N., Calderbank, A.R.: Increasing data rate over wireless channels. IEEE Signal Processing Magazine 17(3), 76–92 (2000)
2. Paulraj, A.J., Kailath, T.: Increasing capacity in wireless broadcast systems using distributed transmission/directional reception. U.S. Patent 5 345, 599 (1994)
3. Foschini, G.J.: Layered space-time architecture for wireless communication in a fading environment when using multi-element antennas. Bell Labs Tech. J., 41–59 (Autumn 1996)
4. Nee, V., Prasad, R.: OFDM wireless multimedia communications. Artech House, Boston (2000)

5. Han, S., Lee, J.: PAPR Reduction of OFDM Signals Using a Reduced Complexity PTS Technique. IEEE Signal Processing Letters 11(11), 887–890 (2004)
6. Daoud, O., Qawasmi, A.-R.: Efficient Performance of COFDM-Based DVB-T. In: IEEE SSD 2009, 6th International Multi-Conference on Systems, Signals & Devices, Tunisia (March 2009)
7. Daoud, O., Alani, O.: Reducing PAPR by utilization of LDPC code. IET Communication Proceedings 3(4), 520–529 (2009)
8. Xilinx- manufacturer of FPGA silicon and development tools, `http://www.xilinx.com` (Last accessed, 11/03/2009)
9. Xilinx ISE, `http://www.xilinx.com/ise/logic_design_prod/webpack.htm` (Last accessed, 11/03/2009)