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# Enhanced Video Streaming over COFDM based Wireless LANs using combined Space Time Block Coding and Reed Solomon Concatenated Coding

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*Abstract*— **In this paper, an enhanced system for video streaming over Wireless LANs at 5GHz (IEEE802.11a/g and Hiperlan/2) is presented. The proposed system employs Space Time Block Codes (STBC) combined with a Reed Solomon (RS) - Convolutional concatenated coding scheme in order to provide reliable transmission of MPEG2 streams without strong reliance on ARQ. PER performances are presented and throughput enhancements are evaluated via link adaptation for different RS correction capabilities (8 and 32 bytes) and different STBC configurations (2Tx-1Rx and 2Tx-2Rx). The proposed system with a 2Tx-2Rx STBC and a 32 byte correction capability RS code allows a gain of 10dB over the standard performance of IEEE802.11a and 2dB over a 2Tx-2Rx STBC system for a PER of $10^{-2}$.**

## I. INTRODUCTION

Recently, there has been a growing interest in video streaming over Coded Orthogonal Frequency Division Multiplexing (COFDM) based Wireless Local Area Networks (WLANs) such as IEEE802.11a/g and Hiperlan/2 [1], [2] and [3]. They provide data rates up to 54Mbit/s in a 20MHz bandwidth and are therefore a solution for home entertainment, video on demand and other home multimedia communication products.

In order to enhance the radio performance of the PHY layer of such WLANs, multiple transmit and receive antennas can be used to provide diversity. A simple and very attractive form of Space Time Block Codes (STBC) was proposed recently by Alamouti in [4]. It only requires a little additional complexity and is suitable for the low mobility environments in which WLANs will be deployed. STBC can enhance performance by exploiting spatial diversity. Forward Error Correcting (FEC) codes are also well known to add robustness and to improve PER/BER performances. Reed Solomon codes (RS) [5] concatenated with convolutional codes have already been implement in Digital Video Broadcasting Terestrial and Satelitte ( [6] [7]) systems where ARQ is not employed. DVB uses the MPEG2 system and allows several data streams to be multiplexed.

ARQ is a mandatory features of the IEEE802.11 Medium Access Control (MAC) layer [8] to detect radio collision. The idea of this paper is to combined the FEC encoded MPEG2 streams with a STBC modified version of the IEEE802.11a PHY layer in order to add robustness, to improve further the PER performances and therefore to reduce the use of ARQ for erroneous received packets. In section II, a short overview of WLANs at 5GHz is given. Section III describes the basis of Space Time Block Codes. Our system is presented in section V. The PER and throughput performances are shown in section VI. Finally, section VII concludes the paper.

## II. WLAN PHYSICAL LAYERS

IEEE802.11a/g [9] [10] and Hiperlan/2 [11] have a similar PHY layer. They both are based on the use of COFDM and include an interleaver and a convolutional encoder. COFDM is used to combat frequency selective fading and to randomize the burst errors caused by wireless channels. OFDM modulation is implemented by means of an inverse FFT. 48 data symbols and 4 pilots are transmitted in parallel to form one OFDM symbol. In order to prevent Inter-Symbol Interference (ISI), a guard interval is inserted by means of a cyclic extension [12] [13]. When the guard interval is longer than the excess delay of the radio channel, ISI is eliminated. In such case, the received signal after the FFT is therefore:

$$y_k = H_k.x_k + n_k \quad (1)$$

where $y_k$ is the received signal on the $k^{th}$ sub-carrier, $H_k$ represents the frequency response of the channel at the $k^{th}$ sub-carrier and $n_k$ represents the complex Additive White Gaussian Noise (AWGN). $x_k$ is the transmitted signal on the $k^{th}$ subcarrier.

The actual data throughput depends on the Medium Access Control (MAC) protocol employed. Both standards are packet-based but differ in their MAC structure [14]. Hiperlan/2 uses a synchronous access with Time Division Duplex/Time Division Multiple Access (TDD/TDMA) and a 2ms MAC frame along with a fixed packet size of 54 bytes [15]. IEEE 802.11a/g uses the IEEE802.11 MAC [8] based on an asynchronous access technique: Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) with a variable length frame format (up to 4096 bytes). Selective Repeat ARQ is used for retransmission of erroneous packets for Hiperlan/2. The legacy IEEE 802.11 implements a mandatory Stop and Wait ARQ

TABLE I

MODE DEPENDENT PARAMETERS FOR WLANS AT 2.4 AND 5 GHZ

| *Mode* | *Modulation* | *Coding rate* | *Nominal bit rate (Mbit/s)* |
|---|---|---|---|
| 1 | BPSK | 1/2 | 6 |
| 2 | BPSK | 3/4 | 9 |
| 3 | QPSK | 1/2 | 12 |
| 4 | QPSK | 3/4 | 18 |
| 5 | 16QAM (H/2 only) | 9/16 | 27 |
| 5 | 16QAM (IEEE only) | 1/2 | 24 |
| 6 | 16QAM | 3/4 | 36 |
| 7 | 64QAM | 3/4 | 54 |
| 8 | 64QAM (IEEE only) | 2/3 | 48 |

used for retransmission of erroneous packet and for collision detection.

The physical layer provides several operating modes depending on the coding rate and the modulation scheme (8 for IEEE802.11a and 7 for Hiperlan/2, see Table I). This mode is chosen with a *Link Adaptation* algorithm. A simple approximation for the link throughput is given by:

$$Throughput = R.(1 - PER) \tag{2}$$

where *R* is the nominal bit rate and *PER* the packet error rate for a specific mode and power. A simple link adaptation algorithm would choose the mode with the highest throughput for a given *C/N*.

## III. SPACE-TIME BLOCK CODING

In [4], Alamouti proposed a simple transmit diversity scheme which was generalised by Tarokh in [16] to form the class of Space-Time Block Codes (STBC). This type of codes achieves the same diversity advantage as Maximal Ratio Receive Combining (MRRC) with 3dB loss due to power normalisation. In Alamouti's encoding scheme, two signals are transmitted simultaneously from two transmit antennas and received with one or two receive antennas. The transmission matrix is given by ( [4] [16]):

$$X = \begin{bmatrix} x_{1,k} & -x_{2,k}^* \\ x_{2,k} & x_{1,k}^* \end{bmatrix} \tag{3}$$

where $x_{1,k}$ and $x_{2,k}$ are the transmitted signals of two consecutive OFDM symbols respectively, at a given sub-carrier *k* before being input to the IDFT and after the serial to parallel conversion (S/P).

At the first antenna, for the $k^{th}$ sub-carrier, $x_{1,k}$ is transmitted during the first symbol period followed by $-x_{2,k}^*$ in the second symbol period. At the second antenna, $x_{2,k}$ is transmitted during the first symbol period followed by $x_{1,k}^*$ in the second symbol period. Each antenna transmits one OFDM symbol with half power compared to the standard IEEE 802.11a system (SISO).

At receive antenna 1, after the DFT and the cyclical prefix removal, the received signal is given by [4]:

$$y_{1,k} = x_{1,k}.H_{1,k} + x_{2,k}.H_{2,k} + n_{1,k} \tag{4}$$

$$y_{2,k} = -x_{2,k}^*.H_{1,k} + x_{1,k}^*.H_{2,k} + n_{2,k} \tag{5}$$

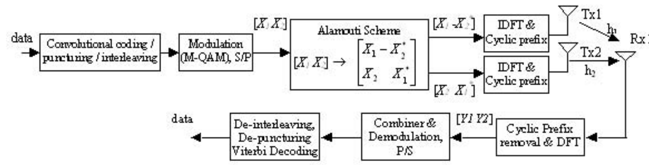



Fig. 1. 2Tx-1Rx STBC block diagram for IEEE802.11a PHY layer

where $n_{1,k}$ and $n_{2,k}$ represent the AWGN and $H_{1,k}$ and $H_{2,k}$ represents the frequency responses for sub-carrier *k* of the channels between Tx 1 and Rx 1 and between Tx 2 and Rx 1 respectively.It is assumed that the channel responses are uncorrelated and remain constant during the period of two OFDM symbols. With an ODFM period of $4\mu s$ in WLANs, this assumption is reasonable for an indoor system.

After channel estimation, channel parameters are known to the receiver and according to [12] and [17], $y_{1,k}$ and $y_{2,k}$ can be combined into:

$$s_{1,k} = y_{1,k}.H_{1,k}^* + y_{2,k}^*.H_{2,k} \tag{6}$$

$$s_{2,k} = y_{1,k}.H_{2,k}^* - y_{2,k}^*.H_{1,k} \tag{7}$$

By using equations (4) and (5), (6) and (7) are rewritten as:

$$s_{1,k} = x_{1,k}(|H_{1,k}|^2 + |H_{2,k}|^2) + n_{1,k}.H_{1,k}^* + n_{2,k}^*.H_{2,k} \tag{8}$$

$$s_{1,k} = x_{2,k}(|H_{1,k}|^2 + |H_{2,k}|^2) + n_{1,k}.H_{2,k}^* - n_{2,k}^*.H_{1,k} \tag{9}$$

In order to perform Soft Decision Viterbi decoding, the Channel State Information (CSI) of both channels and for all the sub-carriers ($H_{1,k}$,$H_{2,k}$) is passed to the decoder in order to calculate the metric.

Figure 1 describes the block diagram for a 2Tx-1Rx STBC configuration that will be used as the inner part of the combined system. In [12], the authors showed that a 2Tx-2Rx system can achieve 8.5 dB gain for mode 1 compared to a standard 1Tx-1Rx system over IEEE802.11a for a packet size of 54 bytes.

## IV. VIDEO STREAMING

The Motion Picture Expert Group (MPEG) has developed the H.262 video encoding scheme [18], known as MPEG2. However, MPEG2 is also generic for audio/visual coding applications and includes error resilience for broadcasting. In parallel to the coding efficiency, the MPEG group has developed a system layer specification [19] [20] describing how MPEG2-compressed video and audio data streams may be packetised and multiplexed together to form a single data stream. Multiple programs can therefore be delivered simultaneously without requiring them to have a common time base.

The system layer approach defines a first class of streams: Packet Elementary Streams(PES). PES packets are limited to 64 kbits and are formed with a variable length header and a variable length payload. The payload contains data sequentially taken from the original data streams (video, audio or system data) to mulipltex. PES packets are then divided

TABLE II

SYSTEM PACKET LENGTH

| *Correction Capability* | *TS packet length (bytes)* | *RS Encoded Packet Length Input to PHY* (bytes) | *Coding ratio* |
|---|---|---|---|
| No RS | 188 | 188 | 1 |
| 8 bytes | 188 | 204 | 0.92 |
| 32 bytes | 188 | 252 | 0.74 |

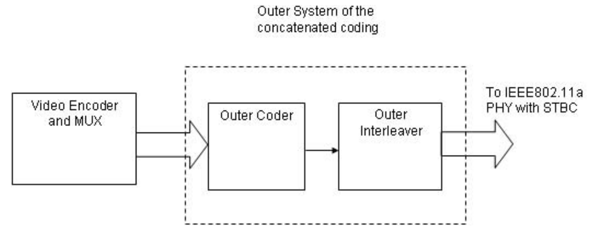



Fig. 2. Outer Coder of the System

and/or multiplexed to create either a Programme Stream (PS) with variable length packets aimed at storage, or to create a Transport Stream (TS) with 188 fixed byte packets aimed at transmission over error-prone environments. In this paper, we have chosen a packetisation in TS packets since we focus our study on video transmission. A TS packet is composed of a 4 byte header containing synchronisation and transport information and a 184 byte video payload [19]. As TS packets are short and have fixed length, they are less susceptible to errors and therefore offer robustness.

TS packets in error are concealed or re-sent with ARQ. Concealment can provide good results but is not efficient enough since concealment techniques only interpolate the missing parts of the pictures and create visual artefacts. On the other hand, ARQ is not desirable since it introduces delays and jitter that are not desirable for time-bounded video transmission. The aim is therefore to minimise the use of ARQ and to apply strong and robust concealment techniques when the number of ARQ exceeds a given threshold.

## V. PROPOSED SYSTEM: COMBINED STBC AND CONCATENATED REED SOLOMON ENCODING

Similar to Digital Video Broadcasting Terrestrial and Satellite (DVB-T [6] and DVB-S [7]) using MPEG2 Transport Stream (TS) packets, we have implemented a concatenated coding scheme with an outer shortened Reed Solomon [5] along with an outer interleaver after the video encoder and prior to the PHY layer. The proposed system is therefore composed of the outer RS code with two different correction capabilities (8 and 32 bytes) and with an outer interleaver combined with a STBC system (2Tx-1Rx and 2Tx-2Rx) at the PHY layer. The convolutional encoder and the interleaver of the PHY layer form the inner part of the concatenated code. The reference system for our simulation is the standard IEEE 802.11a PHY layer without the RS encoder and without STBC. Figures 1 and 2 show an example of block diagrams of the inner and outer coders respectively of the combined system with a 2Tx-1Rx configuration.

We recall that TS packets are 188 bytes long and are input to the outer RS encoder. The encoded packets, with length 204 bytes or 252 bytes depending on the correction capabilities chosen, are then input to the modified IEEE 802.11a PHY layer implementing a 2Tx-1Rx or 2Tx-2Rx STBC (see Table II).

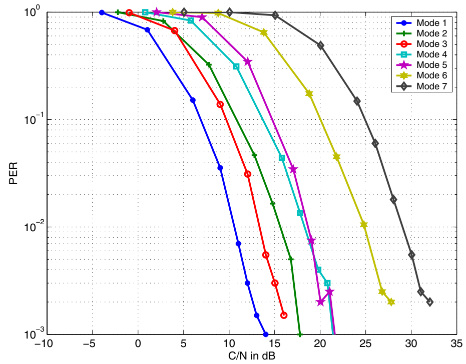
## VI. PERFORMANCE RESULTS

As mentioned in Table II, the 8 and 32 byte correction capabilities of the concatenated encoders lead to coding rates of 0.92 and 0.74 respectively. This will reduced the available bit rate at the application layer. Figure 3 shows the PER performances of the system with a 2Tx-2Rx configuration for the different correction capabilities and for the 7 modes. As expected, the RS encoder improves the PER performance. For example, a PER of $10^{-2}$ with mode 5 requires a C/N of 11dB without an RS code, whereas, it only requires 9.5dB and 8dB for RS codes with correction capatilities of 8 and 32 bytes respectively.

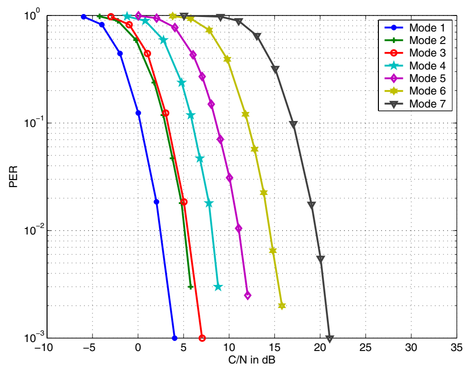
Figure 4 shows the throughput performances used for the link adapation for all the modes and for the 2Tx-2Rx configuration. We can see that the available bit rate at the application layer will be lower for RS(188, 252, t=32) than for RS(188, 204, t=8) since more PHY data are sent for the same amount of application data. For example, the maximum throughput achievable for mode 5 is around 18 Mbits/s for a correction capability of 32 bytes, whereas the 8 byte correcting code allows a maximum of 22 Mbits/s. The nominal bit rate for mode 5 is 24 Mbits/s.

Figure 5 shows the PER performances of the combined system for mode 3 for the 2Tx-1Rx and 2Tx-2Rx STBC configurations and for the two correction capabilities. We can see that the 2Tx-1Rx and the 2Tx-2Rx STBC configurations without RS encoding provide an improvement of 3.5dB and 8dB respectively over the IEEE802.11a standard for a PER of $10^{-2}$. The proposed combined system with a 2Tx-1Rx configuration offers a further 1.5dB and 2.5dB gain with 8 and 32 byte correction capabilities respectively, leading therefore to a 5dB and 6dB gain over the standard. The 2Tx-2Rx configuration offers a 8.5dB and 10dB gain over the standard with the 8 and 32 byte correction capabilities respectively. For a given C/N, the stronger RS code with a 2Tx-2Rx configuration will reduce considerably the PER and reduce therefore the undesirable use of ARQ for video time-bounded transmission.

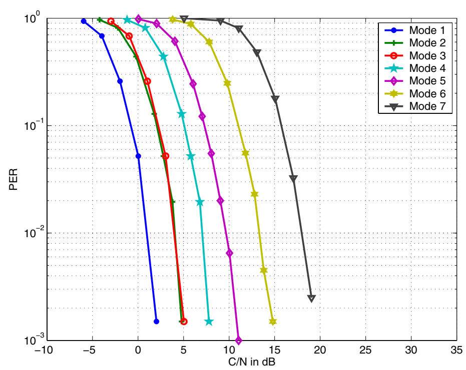
Figure 6 shows the different throughputs achievable with 2Tx-1Rx and 2Tx-2Rx and with the two correction capabilities for mode 3. We can see that for a given STBC configuration, the RS code with the highest correction capability (32) provides the highest throughput for low C/N values. This means that the strong RS code will provide good performance for low C/N levels. However, since this correction capability has a lower maximum throughput, smaller correction capabilities give better throughput as the C/N increases. This means that as the C/N increases, the PER decreases and a strong RS code



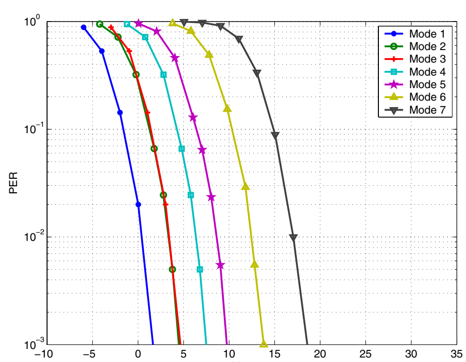

(a) no RS, no STBC PHY length = 188 bytes




(b) no RS, 2Tx-2Rx, PHY length = 188 bytes

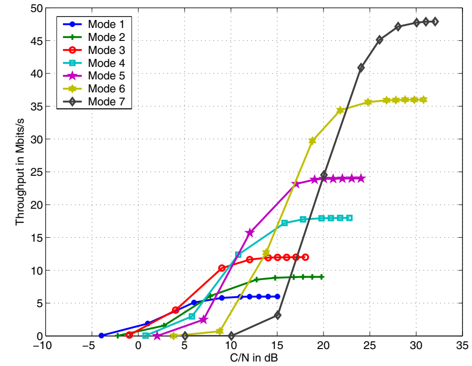



(c) RS(188,204,t=8), 2Tx-2Rx, PHY length = 204 bytes

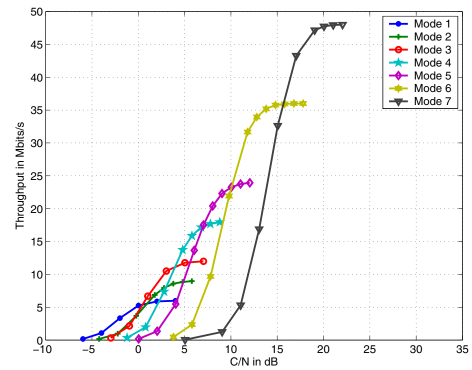



(d) RS(188,252,t=32), 2Tx-2Rx, PHY length = 252 bytes

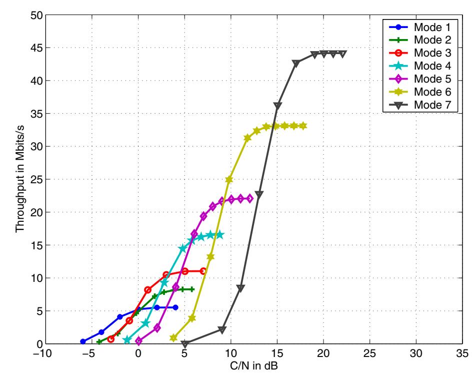
Fig. 3. PER performances for a 2Tx-2Rx STBC and different correction capabilites



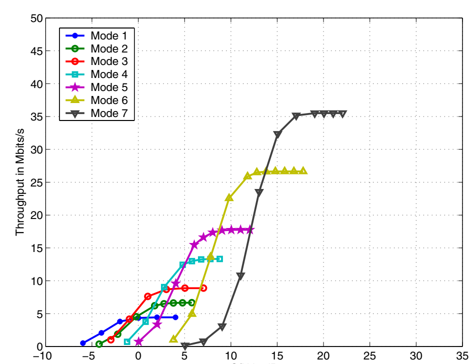

(a) no RS, no STBC, PHY length = 188 bytes




(b) no RS, 2Tx-2Rx, PHY length = 188 bytes




(c) RS(188,204,t=8), 2Tx-2Rx, PHY length = 204 bytes




(d) RS(188,252,t=32), 2Tx-2Rx, PHY length = 252 bytes

Fig. 4. Link Adaptation for a 2Tx-2Rx STBC and different correction capabilities

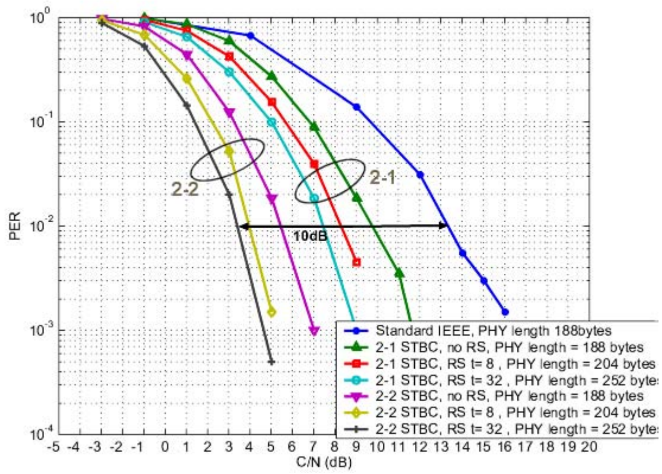



Fig. 5. PER Performance of the proposed system for mode 3 - Channel A

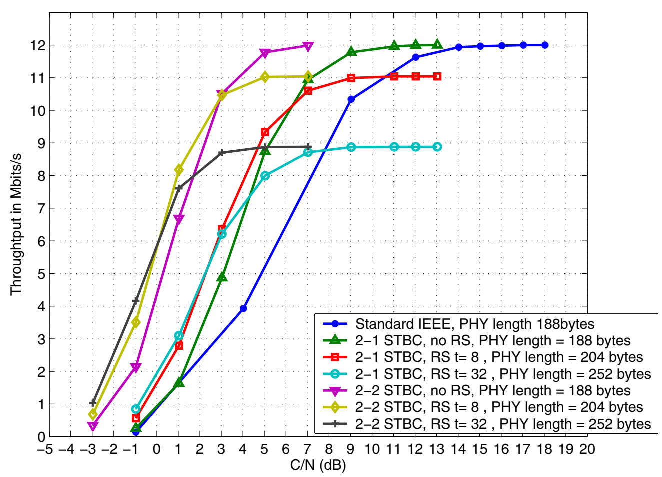



Fig. 6. Throughput Comparison of the proposed system for mode 3 - Channel A

is not necessary any more. A lower correction capacity code would now provide better throughput performance. Finally, as the PER gets closer to zero, the use of RS codes are longer needed to provide good throughput performance.

## VII. Conclusion

In this paper, an enhanced MPEG2 streaming solution for transmission over COFDM based WLANs with combined STBC and RS concatenated coding is examined. At the expense of a lower video bit rate, the proposed system enables reliable video streaming transmission with a minimised use of ARQ by improving the performance of the standard IEEE802.11a/g. The number of packets to retransmit with the mandatory ARQ feature of the IEEE802.11 MAC will be considerably reduced for a given C/N. ARQ is not desirable for time bounded applications such as video and the presented system therefore enhances the video streaming transmission for lower video bit rates. The analysis of the PER performances and the throughput evaluations of the different combinations of STBC configurations (2Tx-1Rx and 2Tx-2Rx) and the RS correction capabilities (8 and 32 byte) shows considerable PER improvement over the simple IEEE802.11a standard (around 10dB for a PER of $10^{-2}$) at the expense of a lower achievable video bit rate.

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