ANALYSIS OF IEEE 802.11N-LIKE TRANSMISSION TECHNIQUES WITH AND WITHOUT PRIOR CSI FOR VIDEO APPLICATIONS

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ABSTRACT

Previous research into MIMO systems has focused little on optimisation for video transmission. In terms of multimedia transmission, spatial multiplexing (SM) is commonly proposed as the most suitable MIMO technique. Most SM-based video transport schemes look to exploit the multiplexing gain, which comes at the expense of a relatively high SNR, unless the channel state is known at the transmitter. Space-time block coding (STBC) is an attractive technique that does not provide the mapping flexibility of SM techniques, but does dramatically reduce the packet-error rate. This paper compares these techniques in terms of decoded video quality through simulations based on practical transmission scenarios. The use of multiple-description coding (MDC) is further proposed to provide a new class of wireless video transmission algorithms.

***Index Terms*—**Multimedia communication, MIMO systems, error-resilient video coding, multiple-description coding (MDC), video mapping

1. INTRODUCTION

To meet the increased demands of future multimedia services, an innovative approach using MIMO (multiple-input-multiple-output) systems has emerged in recent years and is now the topic of standardisation via bodies such as the IEEE (802.11n and 802.16). A significant increase in throughput is provided, even in highly challenging locations and at extreme ranges [1].

The multiple wireless spatial sub-channels can be used to aid the trade-off between robustness and throughput. The case of multiple path video transmission has been studied in great detail for the case of wireline transport [2-4]. However, when MIMO architectures are coupled with typical wireless channel scenarios, a more varied set of error conditions results than is the case with their wireline counterparts. Although some authors have addressed this problem [5-7, 13, 14, 17], the key issue of video decomposition and mapping onto MIMO sub-channels and the adaptation of MIMO to match the quality requirements of video remains an open problem.

Splitting the original bit stream into several independent streams and then recovering these at the receiver is known as Spatial Multiplexing (SM) [8]. An alternative approach to SM, Space Time Coding (STC), applies forward error correction in the spatial domain, with redundant data streams sent from additional transmit antennas [9]. The use of spatial coding helps protect the video stream from channel induced errors in a wireless environment.

Many MIMO systems only require knowledge of the CSI (channel state information) at the receiver. However, when prior CSI knowledge is available at the transmitter, a range of enhanced MIMO configurations are possible. This paper investigates the influence of prominent MIMO architectures, coupled with common channel scenarios, on the quality of transmitted video. The primary aim is to assess the performance of different MIMO techniques under various conditions and outline the underlying compromises that need to be made. Improvements are suggested that enhance the quality of the received video signal.

2. ERROR-RESILIENT MULTIPATH VIDEO TRANSMISSION

The video coding methods adopted here are based on the H.264/AVC standard [10]. Two forms of FMO (flexible macroblock ordering) are used in the simulations presented below. The first, known as slice interleaving, simply places odd rows and even rows of MBs onto different sub-channels. The other, known as the dispersed mode, allocates MBs to slice groups in a checkerboard fashion. This latter technique is particularly suitable for efficient error-concealment [10, 11]. The overhead associated with these two basic error-resilience techniques is very small.

Error-free video quality can be traded off against additional, encoder-centred techniques. For example, the simple yet efficient technique of placing a certain fixed number of Intra coded MBs per picture can help cope with error propagation.

MDC (multiple-description coding) has emerged in recent years as a means of improving video robustness in the presence of path diversity [3]. The purpose of MDC is to introduce redundancy at the encoder to combat errors introduced in the channel [3, 12]. The generated descriptions are correlated and of equal importance, and can reconstruct video of acceptable quality independently. MDC has evolved from the on-off signaling case and has been adapted to lossy packet networks [12]. Extension to the wireless environment using MIMO systems provides significant opportunity for further performance gain [13, 14, 17].

SG-MDC (Slice Group-based MDC), based on the Slice Group coding tool of the H.264/AVC standard [10], is used in this paper. A special version of this form of MDC, which uses three motion-compensation loops (3-L SGMDC), as described by Wang et al. [12], has been chosen here because of its flexibility. This is reflected in its efficient trade-off between central-decoder quality and redundancy levels. The structure of the 3-L SGMDC encoder used in the simulations is shown in Figure 1 and will briefly be described here.

Three inter-connected encoders are used instead of two independent encoders [12]. The central encoder corresponds to an SDC (single description) encoder, while the side encoders help maintain two additional motion compensation loops. For each of the two side encoders there are three encoding parameters that affect the results: (i) quantisation parameter Q_0 for one of the slice groups of the central encoder, (ii) Q_A for the same slice group encoded coarsely in the side encoder (actually, the difference between the two predictions in the central and the side encoder is encoded here) and (iii) Q_B for the other slice group. Both parameters Q_A and Q_B affect the side quality, which results in greater flexibility in trading redundancy against central decoder quality, as shown in Figure 2 for the case of “Paris” CIF sequence (300 frames, fixed central and side QP, balanced channels). It demonstrates how the error-free quality can be traded off against increased error-resilience. Experiments that follow use one single set of MDC parameters when comparing its performance to the SDC one. However, based on Figure 2, it should be clear that this performance can be altered by fine-tuning a certain number of parameters while maintaining the same average video bit-rate. In order to ensure a fair comparison between MDC and conventional SDC video transmission, the video source is encoded at the same average bit-rate for both MDC and SDC cases.

From Figure 3 (the “Foreman” CIF sequence, random packet-error generator, unbalanced channels) it can be seen that treating video like any other type of digital data through splitting the packets into odd and even packets, and then transmitting them over the two sub-channels (Experiment 1) gives the worst performance among those methods considered here. This underscores the need for channel-aware video coding. FMO (dispersed mode) improves the decoded quality by approximately 2dB over a wide range of PERs (Experiment 2). Advanced concealment techniques (Experiment 5) [11] improve upon these two baseline encoding techniques by up to 2-3dB, whilst maintaining the same error-free quality (41dB, not shown in this graph). This is further improved through forced random insertion of Intra coded MBs (Experiment 3). The latter approach has proven to be an efficient way to cope with error-propagation and is obtained at the expense of decreased error-free quality (39dB). However, if the identical video bit-rate constraint is imposed upon MDC (Experiment 4), it gives further enhancement. Improvements over Experiment 3 in the case of unbalanced channels are around 2-3 dB. This demonstrates the superiority of the proposed MDC scheme over conventional, SDC video transmission. However, as will be shown, the actual performance is largely dependent on the chosen MIMO technique and the channel conditions.

3. PROPOSED SYSTEM MODEL AND SIMULATION

For this study, an 802.11a/g WLAN physical (PHY) layer simulator employing MIMO techniques [16], [14] was utilised to evaluate the WLAN PER performance. The physical layer provides a number of link-speeds, each with a different coding and modulation configuration. The method employed for corrupting the transmitted video stream is to discard corrupted packets. Although other methods based on improved FEC or the use of ARQ may give better results, this simple technique is very valuable because of its low latency, which makes it applicable to broadcasting, where ARQ cannot be employed. The PHY layer used in the simulations employs powerful channel coding. However, when bit-errors occur, the corresponding packet is dropped at the receiver. Further protection is offered at the application layer by virtue of advanced error concealment tailored to MDC [15].

The PHY layer simulations have been conducted for both the STBC and SM cases. The SM case considers a technique that does not require prior CSI (zero forcing, ZF, consisting of inverting the channel matrix at the receiver) together with SVD (singular value decomposition), which requires prior CSI at the transmitter to remove inter-stream interference.

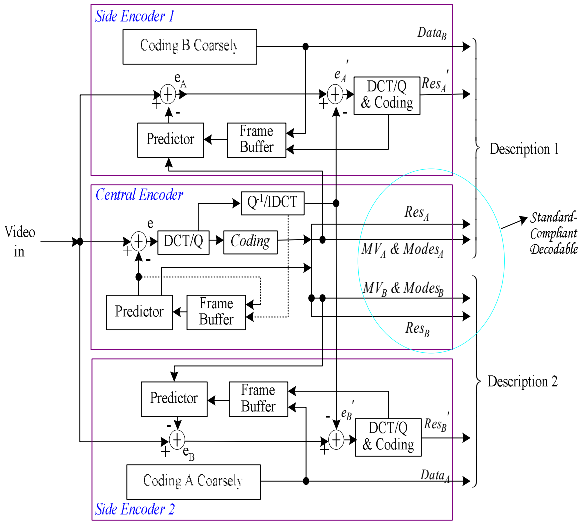

Figure 1. Structure of the proposed 3 Loop MDC scheme.

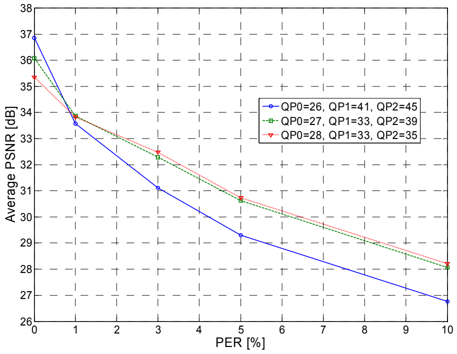

Figure 2. "Paris" CIF sequence, average video bit-rate approx. 770kbps, different MDC parameter sets.

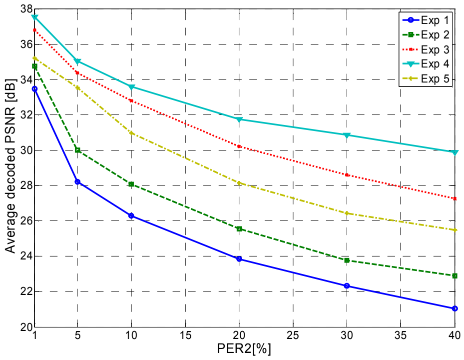

Figure 3. “Foreman” sequence, 300 frames, unbalanced case, PER_1=1%.

When SM is used to transmit video over a 2×2 MIMO system, the encoder outputs two sub-streams (either two slice groups in the SDC-FMO case, or two descriptions in the MDC case), which are then transmitted independently over the two sub-channels. It is well-known that STBC outperforms SM-based techniques in terms of average PER. This result is of great importance; especially since STBC is a simple technique that does not require prior CSI knowledge. However, STBC does not offer any multiplexing gain and cannot support multiple users in a straightforward SM-like manner. This becomes a serious issue, not least for the case of MIMO systems of higher rank. Hence, one of the aims of this paper is to investigate how STBC-based video transmission (which provides no multiplexing gain) compares to sending higher-quality video using SM (which will have a higher PER than STBC for the same SNR). We stipulate that, if SM systems are to use the inherent multiplexing gain to its fullest and provide STBC-like competitive video quality to multiple users, MDC should be deployed to emulate the spatial diversity that makes STBC so successful in dramatically reducing the error-rate.

The simulations have been structured in the following way:

1. SDC video over an STBC system
2. SDC-FMO video over SM systems
3. MDC video over SM systems

Cases 2 and 3 benefit from the multiplexing gain, as opposed to Case 1. This multiplexing gain can be used to double the encoding bit rate, or alternatively to support several (in the 2×2 system in question, two) users. By lowering the bit-rate sufficiently, STBC can also be used to support multiple users, and this will also be investigated.

4. RESULTS

The effects of the described transmission scenarios on the “Foreman” CIF sequence are shown in Figure 4. For these results, transmission mode 5 (16QAM ½ rate) has been employed. The resulting PSNR values have been averaged across the whole sequence and over several different experiments for each SNR. Radio-parameters of the simulated MIMO channel include 50ns rms delay spread in a Rayleigh environment with 360 degrees of angular width at both the transmitter and receiver (spatially uncorrelated channels scenario). The PER performance for the selected transmission mode, channel scenario and relevant packet length of 300 bytes is shown in Figure 5. The performance of STBC and the stronger SVD channel are quite similar, since the stronger singular value follows the fourth-order maximum ratio diversity distribution quite closely [18].

For the case of SVD-based systems, MDC outperforms SDC over the entire range of SNR values given. It also partially outperforms SDC when ZF is used (from SNR=16.5dB upwards). For the range of SNR values of interest for SM, STBC performance is practically error-free. The only case where SM outperforms STBC is when multiplexing gain is used to increase the quality for a single user. It could be argued that this does not justify the use of MDC since the improvements over STBC-SDC are not significant until high SNR values (PERs as low as 1%) are reached [13]. A simple MIMO technique such as STBC coupled with standard SDC may then be a more viable solution.

STBC focuses on full diversity and, as such, does not provide a multiplexing gain. It is however often required to serve multiple users and in this case SM provides an obvious solution. Neither of the SM techniques (with/without prior CSI) provides acceptable quality for this case when SDC video is transmitted (Figure 4). The combination of SM-SVD and MDC technology does however offer one solution to providing video quality of competitive quality.

An alternative solution is to halve the encoding bit-rate while using STBC or beamforming (the stronger SVD channel, corresponding to the greater of the two singular values) to serve two users. Figure 6 compares this performance with the MDC-SVD case supporting two users. A random packet error generator has been used to emulate the relative performance of the MIMO techniques, and MDC parameters have been chosen according to the performance trade-offs in Figure 2.

5. CONCLUSIONS

It has been shown in this paper that for SM-based systems, MDC can outperform SDC. This applies entirely for the case of SVD, and partly so for the case of ZF. It has also been demonstrated that, while STBC/beamforming performance is superior to SM for higher PERs, MDC-SVD can outperform STBC within the quasi error-free range. This would be further emphasised for a higher order MIMO system, where the video would have to be severely distorted to support multiple users using STBC/beamforming. Since these systems are expected to operate in the region of relatively low PERs, this enhanced performance becomes significant and the usefulness of MDC becomes apparent.

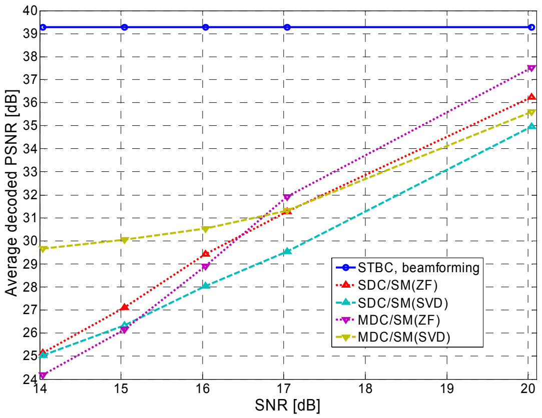

Figure 4. MDC/SDC performance for various MIMO architectures.

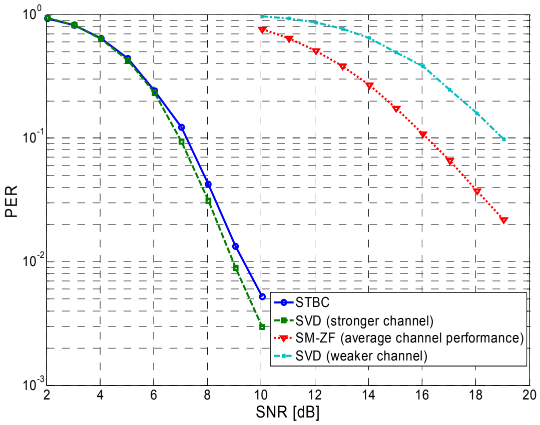

Figure 5. PER performance of different MIMO techniques, Mode 5.

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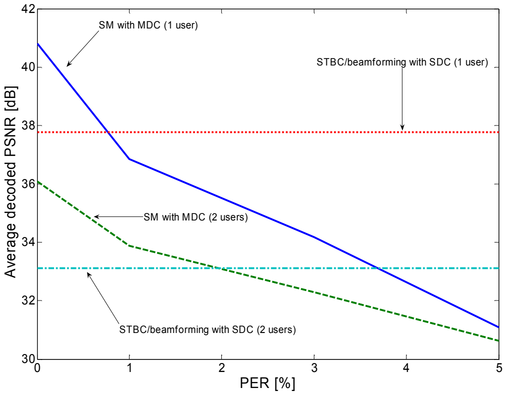

Figure 6. MDC/SDC: various trade-offs for different MIMO architectures.