

Prioritized Transmission of Data Partitioned H.264 Video with Hierarchical QAM

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Abstract

In this Letter hierarchical quadrature amplitude modulation (HQAM) is used to provide unequal error protection (UEP) for layered (data partitioned) H.264 coded video. In a conventional HQAM system, the high priority (HP) and low priority (LP) capacities have a constant ratio, whereas in H.264 data partitioning, the corresponding parts do not necessarily have this constant ratio. This Letter proposes a multilevel HQAM arrangement with adaptive constellation distances, that provides a graceful degradation in the quality of the decoded video without requiring feedback from the receiver. The arrangement improves the quality relative to non-hierarchical transmission through poor SNR channels at the price of a modest quality reduction through good SNR channels.

Index Terms

Layered video transmission, Unequal error protection, Hierarchical constellation.

**EDICS Category: 2.MMSP–Multimedia signal processing and 2.COMM–Signal processing for
communications**

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I. INTRODUCTION

In wireless communications, bandwidth limitations and high probability of error are the two major concerns when transmitting multimedia services. The first problem has been targeted by efficient source coding techniques and by using bandwidth efficient modulation modes. In particular, advanced video compression methods such as H.264/AVC enable the transmission of multimedia services over very low bit rate channels [1]. Efficient modulation modes, like quadrature amplitude modulation (QAM) increase the transmission capacity by assigning more bits to each transmitted symbol. However, the bit error rate (BER) problem still exists, and is exacerbated by the efficient source coding techniques which use variable length coding (VLC) in their compression mechanism, a technique which can be very sensitive to errors.

To address the BER problem there are several error resilient source and channel coding techniques. Among these, layered source coding with prioritized packetization is one of the successful approaches for non-feedback scenarios. This is the focus of this Letter and is achieved by applying unequal error protection (UEP) in which the more important source layers are better protected against errors than the less important layers.

There are several methods of dividing a video bitstream into layers. In this Letter, data partitioning of H.264 is considered since it is included in the current specification [2] and does not significantly increase the bit rate, as other layered coding techniques do. To provide UEP one can apply either channel coding techniques (such as BCH, Reed Solomon, Turbo coding) with different levels of protection or

hierarchical QAM (HQAM). HQAM is a simple and efficient approach in which a non-uniform signal-space constellation is used to give different degrees of protection [3], [4]. The advantage of this method is that different degrees of protection are achieved without an increase in bandwidth, in contrast to channel coding that increases the data rate by adding redundancy. Nevertheless, channel coding techniques achieve excellent protection in very poor channel conditions. A combination of these two methods can take advantage of both. In this Letter we concentrate only on hierarchical modulation as a method of achieving UEP.

One major drawback of conventional HQAM (as in the digital video broadcasting standard for example) is that there are fixed allocated capacities for the high priority (HP) and low priority (LP) video layers (e.g. for 64-HQAM, 33% for HP and 66% for LP). However in data partitioning, the corresponding parts of the coded data do not necessarily produce a constant bit-rate ratio. Therefore, conventional HQAM is not well suited to such application without either accepting delay or losing HP protection. To overcome this problem, a multilevel HQAM arrangement with adaptable constellation distances is proposed, in which the transmitter adapts the constellation distances according to the generated bit ratios. Simulation results show that compared with non-hierarchical methods, the proposed UEP approach provides more effective video transmission through noisy wireless channels.

The remainder of this Letter is organized as follows. A brief overview of H.264 and its data partitioning is given in section II. Section III discusses HQAM followed by the multilevel HQAM arrangement used in the proposed method. An adaptive method for achieving efficient real-time transmission of data partitioned H.264 bitstreams is described in section IV. Finally, simulation results and conclusions are given in sections V and VI respectively.

II. H.264/AVC LAYERED CODING

The H.264 codec consists of two main layers: the video coding layer (VCL) and the network abstraction layer (NAL). VCL provides the core compressed video contents and produces the coded data. NAL performs packetization of the coded bitstream and supports delivery over various types of network.

For layered transmission of the coded video, H.264 supports data partitioning. In this method, the bitstream is divided according to importance into a number of partitions. The first partition carries the most important data (i.e. addressing and motion data), and the other partitions contain less important information (i.e. residual data). In H.264 when using data partitioning, each slice is divided into three partitions (three NAL units). NAL-A is the most important unit, followed by NAL-B and finally NAL-C. Ideally for transmission, each NAL unit should be protected (using HQAM or channel coding) according to its importance. As we are investigating HQAM with two priorities, NAL-A will be considered as the first part, and NAL-B & NAL-C (denoted as NAL-BC) will be grouped in the second part.

III. HIERARCHICAL CONSTELLATIONS FOR M-QAM

A. Two-level hierarchical M-QAM

A conventional square M-HQAM constellation offers two levels of priority, HP and LP, where $M (\geq 16)$ denotes the number of signal points in the constellation. HP data bits occupy the two most significant bits of each point label, and with Gray code labeling, all the points that belong to the same quarter have the same HP bits. LP data bits occupy the rest of the bits in the point label. Figure 1(a) shows such a constellation diagram for 2-level 64-HQAM. To achieve UEP for HP and LP, the distances between quarters (a in Figure 1(a)) and between points inside each quarter b are adjusted such that $a > b$, where the distance factor $\alpha = a/b$. For a given average signal power, increasing the value of α increases the HP protection, but decreases the LP protection. Thus for partitioned video data, when $\alpha > 1$, the HP bits could for example be used to send the NAL-A units leaving the LP bits for the NAL-B and NAL-C

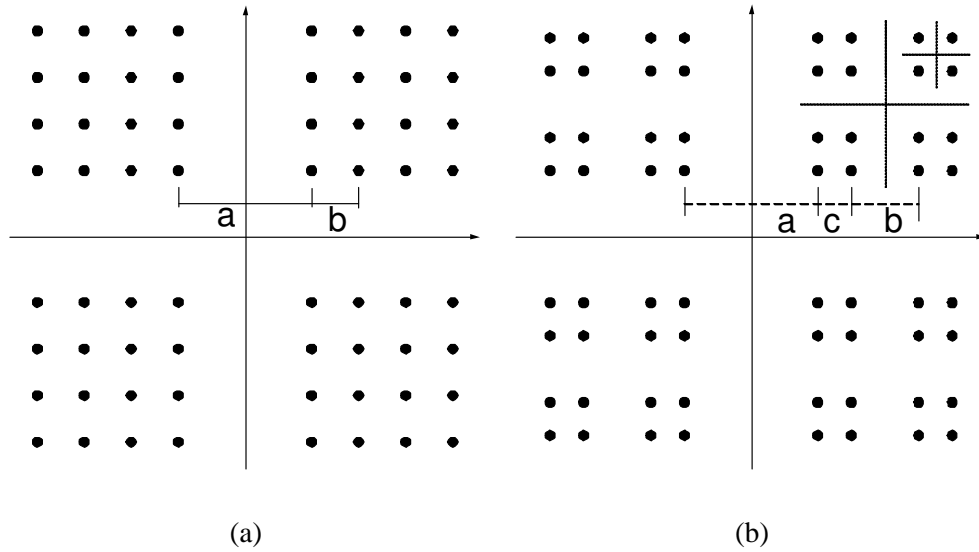


Fig. 1. Hierarchical constellations for 64-QAM, (a) 2-level (b) 3-level.

units.

There are two ratios to consider here: P_S the ratio between the first and second grouping of the source partitioned data (NAL-A/NAL-BC) and P_{HL} the ratio between the available HP and LP transmitted capacities. For example, for 16-QAM, $P_{HL} = 1$ (as there are 2 bits for HP and 2 bits for LP) and for 64-QAM, $P_{HL} = 0.5$ (as there are 2 bits for HP and 4 bits for LP). To guarantee low-delay transmission, P_{HL} should equal P_S , and to minimize storage capacity this equality should be satisfied frame-by-frame. However, with data partitioned H.264 it is not easy to control the ratio between the layers of priority (P_S), as this depends on the source coding bit budget and the picture contents. For example, for a 100 kbps coded Foreman video sequence, the size of NAL-A is a little less than the size of NAL-BC such that P_S is mostly between 0.6 and 0.9. For 64 kbps coded Foreman, the percentage of NAL-A increases such that P_S is between 0.9 and 1.4. If $P_S > P_{HL}$, then to guarantee low-delay transmission (or not waste channel resources) some of the first partition bits must be sent in LP positions within the transmitted packet, which will increase the BER for the first partition. Therefore, what is needed is to increase the HP capacity without compromising its protection. This could be achieved using the following multilevel

TABLE I
HIERARCHICAL MODES BY CHANGING α AND β SHOWING THE CORRESPONDING CAPACITY FOR EACH PRIORITY IN
MULTILEVEL 64-HQAM.

Mode	α	β	Relative capacity		
			high (HP)	mid	low (LP)
1. Non-Hierarchical	1	1	6(100%)		
2. Hierarchical 3-priorities	> 1	> 1	2(33%)	2(33%)	2(33%)
3. Hierarchical 2-priorities	1	> 1	4(66%)	-	2(33%)
4. Hierarchical 2-priorities	> 1	1	2(33%)	-	4(66%)

HQAM arrangement.

B. Multilevel hierarchical M-QAM

In multilevel HQAM [5], [6] the constellation points are placed in such a way that groups of bits within the point label have similar degrees of protection. For example for 64-HQAM, to increase the capacity of HP data without losing protection, the constellation points can be organized to give the first four bits more protection (and so assigned to HP) than the last two bits (assigned to LP). The requisite constellation diagram is shown in Figure 1(b) for 3-level 64-HQAM. Two distance factors are now introduced $\alpha = a/b$, and $\beta = b/c$. This constellation could support three priorities with 2 bits each, but this Letter focuses only on the 2-priority case.

The values of α and β will influence the performance of the system. They can make the system non-hierarchical, hierarchical with two priorities or hierarchical with three priorities (for 64-QAM). Table I shows the possible modes and the corresponding capacities (bits/symbol) for each priority, for 3-level 64-HQAM. Figure 2 shows an example of BER performance for $(\alpha = 1, \beta = 2)$ and $(\alpha = 1.5, \beta = 1)$. The non-hierarchical $(\alpha = 1, \beta = 1)$ performance is also included for comparison.

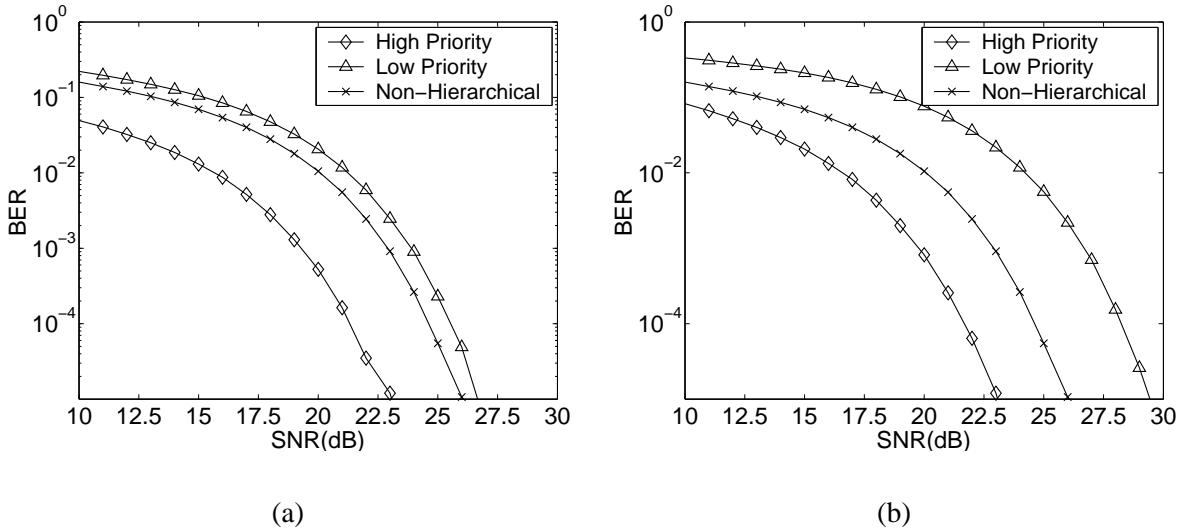


Fig. 2. BER vs. SNR for 2-priority 64-HQAM for (a) $\alpha = 1.5, \beta = 1$, and (b) $\alpha = 1, \beta = 2$.

IV. ADAPTIVE SWITCHING FOR H.264 DATA PARTITIONING

We note that the data partitioned source ratio, P_S , may not always match the channel packet priority ratio, P_{HL} . To overcome this problem, adaptive switching between the modes of Table I could be used according to the values of HP and LP bit rates. For example, if $P_S > P_{HL}$ the system temporarily switches to *mode 3* to increase the HP capacity without losing protection. If $P_S < P_{HL}$ the system uses the conventional arrangement of *mode 4*. If $P_S \ll P_{HL}$ the system switches to *mode 1* and uses all the capacity to send LP bits, hence increases the LP capacity. It should be noted that this adaptive system does not require feedback from the receiver and switching decisions are based on information at the transmitter. The receiver only needs to know which mode (of Table I) is used for each transmitted packet. However, this small signalling information must be well protected, in this Letter it is assumed to be error free.

The performance of such an adaptive 3-level hierarchical 64-QAM system that adapts the constellation distances according to the value of P_S is compared with a fixed 2-priority hierarchical 64-QAM ($\alpha = 2$) that compromises the HP protection. Details of these two representative experimental arrangements are

as follows:

- *Fixed 2-priority 64-HQAM with $\alpha = 2$.* The default assumes $P_S = 0.5$ (2 bits for HP and 4 bits for LP). If P_S increases, the system must borrow LP capacity to transmit HP bits in order to maintain real-time transmission, but the price paid is lower HP data performance. When P_S becomes less than 0.2, the system temporarily stops sending HP data and allocates all the available capacity to LP bits.
- *Adaptive 3-level 64-HQAM.* Here the default uses $(\alpha = 1.5, \beta = 1)$ when $P_S = 0.5$. If P_S increases, the system switches to $(\alpha = 1, \beta = 2)$ which permits the transmission of 4 bits for HP and 2 bits for LP without losing HP protection; the loss is only in LP performance (as seen in Figure 2). If P_S becomes less than 0.5, the adaptive system switches to $(\alpha = 1, \beta = 1)$ and uses all the capacity to send LP data. This provides better protection for LP than the default situation.

For the default case, the fixed system offers more protection for HP data as it uses $\alpha = 2$, while the adaptive system uses $(\alpha = 1.5, \beta = 1)$. The reason of using $(\alpha = 1.5, \beta = 1)$ for the adaptive system is to maintain a consistent BER performance for HP data when switching to *mode 3*. We note that using $(\alpha = 2, \beta = 1)$ will also give good results.

V. SIMULATION RESULTS

A 64-HQAM signal constellation has been used to evaluate the performance of data partitioned H.264 video transmission over a Gaussian channel, with average Peak Signal-to-Noise ratio (PSNR) used as a quality measure. The Foreman video sequence (QCIF@10Hz) was coded at 64 kbps, 100 kbps and 200 kbps.

With data partitioning, the bit rate selected for transmission influences the source data ratio P_S . For a low bit rate, such as 64 kbps, the first partition (NAL-A) will have a similar size to the residual data (NAL-B + NAL-C) for much of the time (i.e. $P_S = 1$). For a high bit rate, such as 200 kbps, the residual

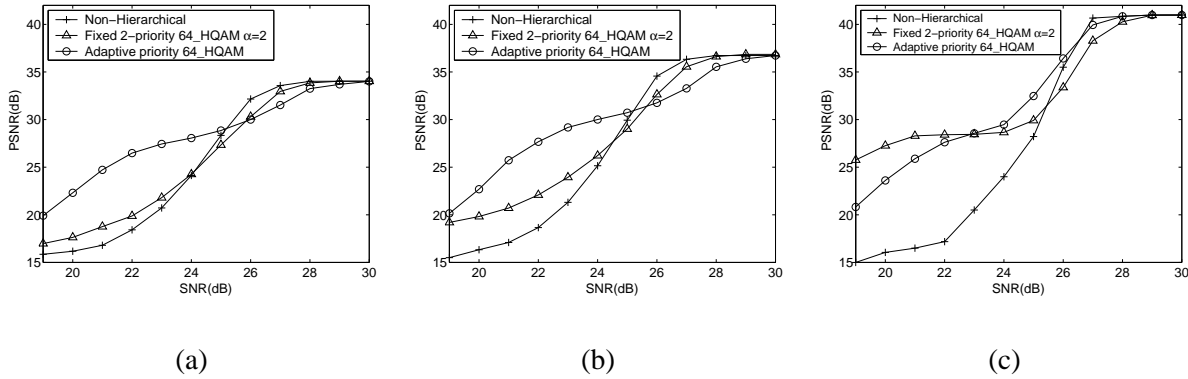


Fig. 3. PSNR for data partitioning for fixed 2-priority and adaptive 3-level hierarchical 64-QAM, in a Gaussian channel, for Foreman (a) 64 kbps, (b) 100 kbps, and (c) 200 kbps.

data will sometimes have a data rate much higher than the first partition (i.e. $P_S \ll 0.5$ for 64-HQAM). Thus, investigating a range of bit rates will show how our adaptation system performs as video statistics change.

Figure 3 shows PSNR performance comparisons between fixed 2-priority, adaptive 3-level and non-hierarchical 64-QAM. For 64 kbps at low channel SNR, fixed 64-HQAM offers little improvement over the non-hierarchical case, because the HP data suffers from high BER. In contrast, the performance of the adaptive system is seen to yield considerable improvement, at the price of some degradation in performance for high SNR. However, the performance gained is seen to be much more than that lost. For 100 kbps, the adaptive system is still better than a fixed system for low channel SNR, but the difference is smaller than that of 64 kbps, as the P_S value will now be lower.

For 200 kbps, P_S will have a lower value for much of the time. Thus, for high channel SNRs when the improving effect of the LP partition becomes established, the adaptive system performs better as it switches to *mode 1* ($\alpha = 1, \beta = 1$), which offers more protection to the LP part. In all cases, the adaptive method gives a graceful degradation as channel SNR decreases.

VI. CONCLUSION

We have analyzed a prioritized method of transmitting data partitioned H.264 bitstreams without losing protection for the high priority data. To optimize video quality for real-time transmission, distances between points in a QAM signal constellation are adapted according to the contents of high and low priority buffers. This adaptation is achieved by using a multilevel hierarchical constellation. Compared with a fixed constellation, the adaptive method yields a considerable improvement in video quality. It also displays a more graceful reduction in performance as channel SNR degrades.

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