# MixCast Modulation for Layered Video Multicast over WLANs

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*Abstract*— **The major challenge in wireless multicast is the heterogeneous channel conditions of multiple users. In video multicast, the combination of a layered video coding scheme and a layered transmission scheme can gracefully accommodate user heterogeneity. This paper presents MixCast, a novel physical layer scheme for layered transmission. The key innovation in MixCast is the rateless Euclidean symbol mapping which mixes base layer and enhancement layer bits into arbitrary number of wireless symbols using arithmetic weighted sum operation. This design brings two benefits when compared with the state-of-the-art physical layer technique known as hierarchical modulation (HM). First, MixCast uses a fixed modulation constellation, avoiding the complexity in adaptive modulation and coding when channel condition varies. Second, the rateless symbol mapping allows MixCast to achieve much smoother rates than the stair-shaped rates in HM. We implemented MixCast for typical video multicast over OFDM physical layer, and evaluate its performance against HM through both simulations and software radio testbed. In simulations, MixCast shows consistent gain of 3dB to 5dB over HM under various rate combinations. In the testbed experiments, MixCast achieves significant gain up to 15dB in video PSNR over HM for football sequence.**

## I. Introduction

The broadcast nature of wireless medium allows a single source to simultaneously communicate information with multiple receivers. For multicast applications, the major challenge arises from the conflicting rate requirements of the receivers due to their heterogeneous channel conditions. In this paper, we are interested in video multicast in wireless local area networks (WLANs). As Fig. 1 shows, the base station (BS) communicates with all users through one-hop connections. Normally, the users close to the BS have better reception quality (strong receivers) and those far apart from the BS have worse reception quality (weak receivers). It has been recognized that, such user heterogeneity can be gracefully accommodated through combining a layered video coding scheme and a layered transmission scheme[7]. In particular, video is encoded into base layer (BL) and enhancement layer (EL) through scalable video coding (SVC) technique[9]. By using a layered transmission scheme, the BS ensures that weak receivers receive BL data so that they can decode video with basic quality, and strong receivers obtain both layers and decode full-quality video.

Layered transmission can be realized at network, MAC, or PHY layers. In WLANs, however, communications from the BS to the users are one-hop, so the network layer approach is no longer applicable. MAC layer approaches transmit BL and EL bits in a time-division or frequency division way [6], [5], [10], while PHY layer approaches superimpose the two layer bits into one wireless symbol and transmit them together. The state-of-the-art PHY layer technique for layered transmission is known as hierarchical modulation (HM) [4], [3], [13], [8]. Although there are several variants of HM [12], [14], such as rotating EL signal to improve the spectral efficiency, all schemes share the same design principle. First, the two layer data are encoded with separate channel coder. Then, the coded bits are mapped to a constellation for transmission. Virtually, the BL and EL data have their respective constellations. The constellation for BL data is more sparse than that for EL data, so that BL bits is more easily distinguishable. The constellation in actual use is the superposition of the two virtual constellations, and it has a hierarchical structure. The quadrature amplitude modulation (QAM) based implementation of HM has been included in the digital video broadcast terrestrial (DVB-T) standard [1].

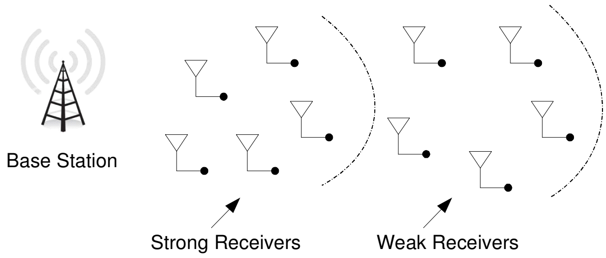



Fig. 1. Layered multicast over WLANs

However, it is well known that wireless channels are time-varying, and the variation could be dramatic when users are mobile. The main complexity in using HM is that the BS has to change the coding and modulation schemes to cope with varying channel conditions. When channel varies dramatically, the BS has to frequent change the radio frequency (RF) circuit settings, which poses a big challenge for practical implementation. In addition, any operative system will only provide limited choices of BL and EL rates. For example, DVB-T standard specifies three BL rates and five EL rates. This creates a stair-shaped rate envelop as opposed to continuously changing channel condition. In many cases, there are non-negligible losses in spectral efficiency.

In this paper, we propose a new PHY layer technique

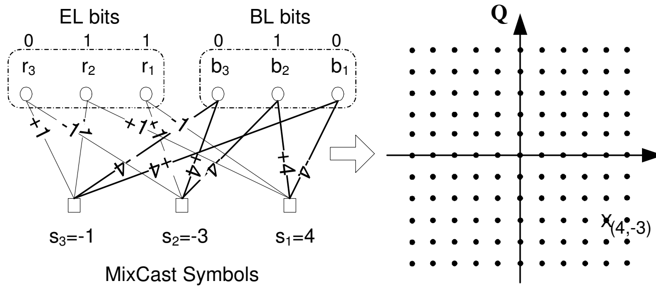



Fig. 2. Euclidean symbol mapping and wireless symbol construction

called MixCast for layered transmission. MixCast uses a fixed modulation constellation and a fixed channel coding rate for all channel conditions, greatly simplifying the BS design. In addition, MixCast is capable of fine-grained rate adaptation through ratelessly adjusting the number of transmitted wireless symbols. The fine granularity allows MixCast to better exploit the channel capacity than conventional HM. We then implement MixCast based on orthogonal frequency division multiplexing (OFDM) physical layer for typical video multicast settings. Performance evaluation is carried out through both simulation and a software radio testbed. Testing on football sequence shows that MixCast achieves up to 15dB gain in video peak signal-to-noise ratio (PSNR) over HM.

The rest of the paper is organized as follows. Section II presents the Mixcast framework and its core component Euclidean symbol mapping. In Section III, MixCast is first evaluated through Matlab simulations, and then over a software radio platform. The comparative results with HM are presented. Section IV concludes the paper.

## II. MixCast for Layered Multicast

MixCast has two major merits. First, it uses a fixed constellation for various channel conditions, which greatly simplifies the RF circuit design at the sender. Second, it achieves fine-grained rate adaption, which allows the communicating parties to fully exploit the channel capacity. These two merits are achieved through a novel bit-to-symbol mapping design which we term as Euclidean symbol mapping.

### A. Sender Design

MixCast at the sender side is composed of three modules. First, the BL bit block and EL bit block are passed through separate channel encoders. We adopt a low-density parity-check (LDPC) code with fixed rate $r_{cc} = 0.9$. This high rate channel code is not used to correct all the transmission errors, but is only used to correct a small amount of demapping errors. The demapping process itself has certain error correction capabilities, which will become clear in the following subsections.

Second, the coded bits of both layers are fed into the Euclidean symbol mapping module, which is the key innovation of this work. Let $N_1$ and $N_2$ be the block length of BL and EL after channel coding. Each MixCast symbol is formed by computing the weighted sum of $L_1$ randomly selected BL bits and $L_2$ randomly selected EL bits. The weights for BL bits have larger absolute values than the weights for EL bits, such that BL bits are easily distinguishable under worse channel conditions. Fig. 2 gives a simple example of the Euclidean symbol mapping. The BL bits are associated with weights +4 or -4, and the EL bits are associated with weights +1 or -1. From the first MixCast symbol $s_1 = 4$, it is easy to deduce that $b_1 = 0$ and $b_2 = 1$, but the values of $r_1$ and $r_2$ are not clear. After several MixCast symbols are received, the transmitted bits can be decoded as $b_1b_2b_3r_1r_2r_3 = 010110$. When channel is noisy, the receiver may obtain noisy versions of MixCast symbols and this may cause demapping errors. However, MixCast allows the sender to generate arbitrary numbers of symbols. When channel condition is poor, more symbols are transmitted and they can provide cross verification to deduce the actually bit values.

The third step is to combine every two MixCast symbols into one wireless symbol. We adopt QAM modulation, and each MixCast symbol is transmitted as the I (in-phase) or Q (quadrature) component of a wireless symbol. As shown in Fig. 2, symbols $(s_1, s_2) = (4, -3)$ are transmitted in one wireless symbol. Because each MixCast symbol is independently transmitted, the channel noise can be faithfully reflected by the difference between the transmitted and received MixCast symbol values. Now, $\frac{M}{2}$ times slots are used to transmit $M$ MixCast symbols, the transmission rate for BL and EL can be computed as:

$$R^b = \frac{2N_1 r_{cc}}{M}; \quad R^e = \frac{2N_2 r_{cc}}{M} \tag{1}$$

From this equation, it is clear that, by varying the value of $M$ (the number of MixCast symbols), the transmission rate can be smoothly adapted.

### B. Weight Design in Euclidean Symbol Mapping

The key design parameter in Euclidean symbol mapping is the weights for BL and EL bits. The following factors should be considered in weight design. First, the size of the weight set ($L_1$ and $L_2$) should be large enough so that each source bit can be sampled by multiple MixCast symbols even when a high transmission rate is targeted ($M$ is small). Besides, in layered video streams, the EL has much higher rate than BL, and the rate ratio between BL and EL streams is around 1:3. We should try to keep the same ratio for $L_1 : L_2$. Second, the difference between BL and EL weighting should be large enough. Usually, we expect that the SNR requirements for receiving BL and EL data differ by around 10dB. Finally, the range of MixCast symbol values should not be too large.

Based on these considerations, we design the following set of weights for layered video multicast.

$$\begin{aligned} \mathcal{W}^b &= \{\pm 6, \pm 6\} \\ \mathcal{W}^e &= \{\pm 2, \pm 2, \pm 2, \pm 1, \pm 1, \pm 1\} \end{aligned} \tag{2}$$

Therefore, we have $L_1 = 4$ and $L_2 = 12$, and the total degree of each MixCast symbol is 16. The expectation of MixCast symbols will be zero and the minimum and maximum values of MixCast symbols are $y_{min} = -21$ and $y_{max} = 21$.

Therefore, we are actually using a dense $43 \times 43$ QAM to transmit the modulated symbols.

### C. Receiver Design

At the receivers, demapping is performed to convert received wireless symbols back to binary bits. Different from HM, the demapping is not performed on per-symbol basis. Instead, the receiver collect a group of MixCast symbols and perform joint demapping. The joint demapping allows MixCast symbols to provide cross verification for each other. The more the MixCast symbols, the higher confidence the receiver will get in demapping. This is the reason why we say MixCast demapping has error correction capabilities, and only a high rate channel coding is needed as the outer code.

Mathematically, the demapping process finds the optimal solution to the following problem:

$$\begin{aligned} \hat{\mathbf{x}} = & \quad \underset{\mathbf{x}\in GF(2^N)}{\arg\max} \; P(\mathbf{x}|\mathbf{y}') \\ \text{s.t.} & \quad \mathbf{y}' = \mathbf{y} + \mathbf{e} = \mathbf{G}\mathbf{x} + \mathbf{e} \end{aligned} \tag{3}$$

where $\mathbf{x}$, $\mathbf{y}$, $\mathbf{y}'$ and $\mathbf{e}$ are the vectors of source bits, generated MixCast symbols, received symbols and channel noise. To reduce the demapping complexity, we adopt a modified belief propagation (BP) algorithm. As known, BP has been used for LDPC decoding. However, in our demapping problem, each MixCast symbol is the arithmetic addition instead of logical XOR of sampled source bits, therefore we design a revised BP algorithm as follows.

In each iteration of BP, connecting source bits and MixCast symbols exchange information. In the $t^{th}$ iteration, the messages from symbol $i$ to source bit $j$ are:

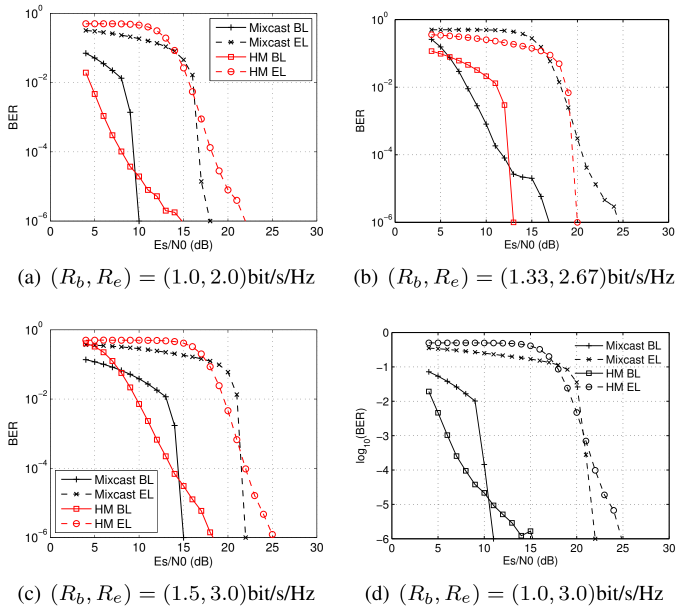
$$\begin{aligned} v_{ij}^{(t)}(0) &= p(x_j = 0|y_i') = p(X_j = y_i') \\ v_{ij}^{(t)}(1) &= p(x_j = 1|y_i') = p(X_j = y_i' - w_l) \end{aligned} \tag{4}$$

where $X_j = r_i - w_l \cdot x_j$ and $j = i_l$. The distribution of $X_j$ is a combinatory probability which is the convolution of distributions of other bits and noise. By using FFT, we convert convolution to simple multiplication in transform domain. The messages from source bit $j$ to symbol $i$ are:

$$\begin{aligned} u_{ji}^{(t)}(0) &= C_{ji} \cdot (1 - p_j) \cdot \prod_{k \in T_j \backslash i} v_{kj}^{(t)}(0) \\ u_{ji}^{(t)}(1) &= C_{ji} \cdot p_j \cdot \prod_{k \in T_j \backslash i} v_{kj}^{(t)}(1) \end{aligned} \tag{5}$$

where $C_{ji}$ is the normalization factor which ensures $u_{ji}^{(t)}(0) + u_{ji}^{(t)}(1) = 1$, and $T_j$ is the index set of the MixCast symbols that are connected with source bit $j$.

After sufficient number of iterations, the value of source bit $j$ is decided to be 1 if $p(x_j = 1) > p(x_j = 0)$, and to be 0 if otherwise. It is now clear that the joint demapping can fully utilize the statistics of channel noise to derive the probability of source bits.




(a) $(R_b, R_e) = (1.0, 2.0)$bit/s/Hz (b) $(R_b, R_e) = (1.33, 2.67)$bit/s/Hz

(c) $(R_b, R_e) = (1.5, 3.0)$bit/s/Hz (d) $(R_b, R_e) = (1.0, 3.0)$bit/s/Hz

Fig. 3. Comparing the BER of HM and MixCast at different rates

## III. Evaluation

### A. Simulation

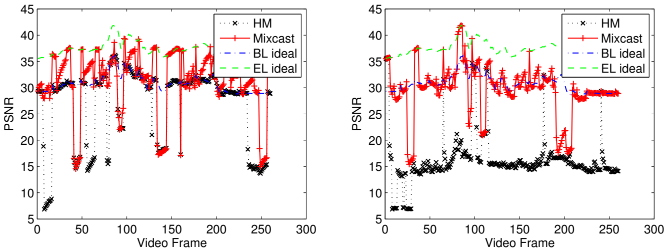
In the Matlab simulations, we keep the BL and EL rate ratio to 1:3 or 1:2, and tested the performance of MixCast for various $M$ from 2400 to 9600. However, since HM only has very limited number of rates, here we only present four sets of results and compare the BER performance of MixCast and HM under the same transmission rate. The four transmission rates $(R^b, R^e)$ and corresponding parameters are shown in table I.

In Hierarchical Modulation, we use QPSK-in-64QAM modulation as defined in DVB-T. In Mixcast, for rate ratio $1:2$, a source block contains $N_1 = 2400$ BL bits and $N_2 = 4800$ EL bits. For ratio $1:3$, the numbers are $N_1 = 1600$ and $N_2 = 4800$. This is why both (1.5, 3.0) and (1.0, 3.0) are achieved by sending 2880 MixCast symbols. In the comparison, we transmit $10^7$ BL bits and $2 \times 10^7$ or $3 \times 10^7$ EL bits over AWGN channel, and count the bit error rate (BER). Fig.III-A shows the BER comparison at different rates. It should be noted that the results should be compared at channel SNRs that achieves less than $10^{-5}$ BER. For a typical PHY packet with length 1K Byte, the packet delivery ratio is about 92% when the BER is $10^{-5}$, and about 99% when the BER is $10^{-6}$. The simulation results in Fig. III-A show that MixCast exhibit significant advantage over HM at low BER region. The gain is about 3dB to 5dB when BER is $10^{-6}$ in all the rate settings.

| $(R_b, R_e)$ | $N_1 : N_2$ | Mixcast M | HM Coding Rate |
|---|---|---|---|
| (1.00, 2.00) | 1:2 | 4320 | (1/2, 1/2) |
| (1.33, 2.67) | | 3240 | (2/3, 2/3) |
| (1.50, 3.00) | | 2880 | (3/4, 3/4) |
| (1.00, 3.00) | 1:3 | 2880 | (1/2, 3/4) |

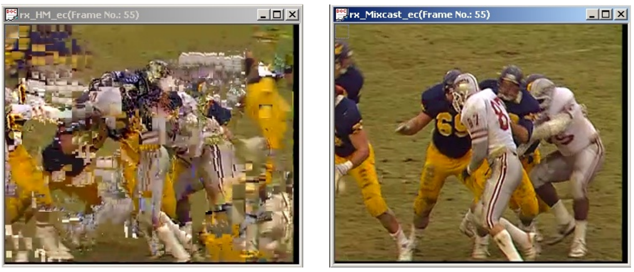
TABLE I

The compared rates and corresponding parameters




(a) Video PSNR in LOS scenario (b) Video PSNR in NLOS scenario

Fig. 4. Layered video transmission over OFDM PHY



(a) HM result (b) MixCast result

Fig. 5. Frame 55 received in LOS scenario by HM and MixCast

### B. Experiment over Software Radio Testbed

The testbed evaluation is carried out based on a software radio platform called SORA [11]. MixCast is implemented over OFDM PHY as specified in 802.11a standard [2]. The channel is divided into 64 subcarriers and 48 of them are used to transmit modulation symbols. We use 150 OFDM symbols in each PLCP frame for data transmission. The NAL unit of BL and EL is divided into 200-Bytes and 600-Bytes blocks respectively. All the other NAL units containing video parameters, like SEI, SPS and PPS, are transmitted at the lowest data rate to ensure reliable transmission.

In the experiment, since it is not possible to repeat wireless channel condition, we perform trace-based experiments instead of real-time experiments to ensure a fair comparison. The channel trace data are generated in two scenarios. One scenario is the Line-of-Sight (LOS) case and both sender and receiver are static. The other scenario is the Non-Line-of-Sight (NLOS) case. We keep the sender static but move the receiver around during data collection. For both scenarios, $4s$ data is traced including noise on pilots and noise on carriers.

The layered video stream is generated by JSVM-9-15 codec, with GOP (group of picture) size 16 and IPP... frame structure. The frame rate is 30 frames per second. We adopt quality scalability by setting BL QP (quantization parameter) to 37 and EL QP to 28. In LOS scenario, the channel SNR is pretty high, so we use transmission rate (1.00, 3.00) bits/s/Hz for both HM and MixCast. In NLOS scenario, a lower rate of (0.50, 1.50) bits/s/Hz is adopted. At the receiver, since any bit error will lead incorrect decoding of entire packet, we drop the packet if any error occurs.

Fig. III-B compares the achieved video PSNR of HM and MixCast. The proposed MixCast has consistent better performance than HM in both scenarios. In LOS scenario, the receiver in HM scheme is able to obtain BL stream most of the time, but does not get any EL frame. MixCast allows a receiver to correctly receiver EL data in around 20% of the frames. Fig. III-B demonstrates the visual quality of the received frame 55 by the two methods in LOS scenario. HM gets only 15dB while MixCast achieves full-quality. In NLOS scenario, the packet loss rate in HM scheme is so high that few frames have full BL quality. In contrast, MixCast allows a receiver to get BL stream most of the time, and several frames are even received with EL data. Therefore, the average PSNR achieved by MixCast is much higher than that achieved by HM, and the gain is around 15dB.

## IV. Conclusion

We have described in this paper a novel PHY layer scheme named MixCast for layered video multicast in WLANs. The two merits of MixCast is the one-size-fits-all modulation constellation and the fine-granularity rate adaptation capability. The fixed dense constellation does not incur performance deterioration even in poor channel conditions because the designed Euclidean symbol mapping can faithfully preserve channel noises and the demapping is jointly performed on a set of received symbols. Both simulation and testbed experiments have demonstrated the superior performance of MixCast in comparison with HM.

## References


[1] *Digital Video Broadcast*. http://www.etsi.org/deliver/etsi_en/300700_300799/300744/01.06.01_60/en_300744v010601p.pdf.

[2] *Part11: Wireless LAN Medium Access Control and Physical Layer Specifications: High Speed Physical Layer in the GHz Band*, 1999.

[3] A. Calderbank and N. Seshadri. Multilevel codes for unequal error protection. *Information Theory, IEEE Transactions on*, 39(4):1234 –1248, July 1993.

[4] K. Fazel and M. Ruf. Combined multilevel coding and multiresolution modulation. In *IEEE ICC'93*, volume 2, pages 1081 –1085 vol.2, May 1993.

[5] J. Kim, J. Cho, and H. Shin. Layered resource allocation for video broadcasts over wireless networks. *Consumer Electronics, IEEE Transactions on*, 54(4):1609 –1616, 2008.

[6] A. Majumda, D. Sachs, I. Kozintsev, K. Ramchandran, and M. Yeung. Multicast and unicast real-time video streaming over wireless lans. *IEEE Transactions on CSVT*, 12(6):524 –534, June 2002.

[7] S. McCanne, V. Jacobson, and M. Vetterli. Receiver-driven layered multicast. In *SIGCOMM '96*, pages 117–130. ACM, 1996.

[8] K. Ramchandran, A. Ortega, K. Uz, and M. Vetterli. Multiresolution broadcast for digital hdtv using joint source/channel coding. *Selected Areas in Communications, IEEE Journal on*, 11(1):6–23, Jan. 1993.

[9] H. Schwarz, D. Marpe, and T. Wiegand. Overview of the scalable video coding extension of the h.264/avc standard. *IEEE Transactions on CSVT*, 17(9):1103 –1120, 2007.

[10] C. Suh and J. Mo. Resource allocation for multicast services in multicarrier wireless communications. *Wireless Communications, IEEE Transactions on*, 7(1):27 –31, 2008.

[11] K. Tan, J. Zhang, J. Fang, H. Liu, Y. Ye, S. Wang, Y. Zhang, H. Wu, W. Wang, and G. M. Voelker. Sora: high performance software radio using general purpose multi-core processors. In *NSDI'09*, pages 75–90. USENIX Association, 2009.

[12] S. Wang, S. Kwon, and B. Yi. On enhancing hierarchical modulation. In *IEEE International Symposium on BMSB*, 31 2008.

[13] L.-F. Wei. Coded modulation with unequal error protection. *Communications, IEEE Transactions on*, 41(10):1439 –1449, Oct. 1993.

[14] H. Zhao, X. Zhou, Y. Yang, and W. Wang. Hierarchical modulation with vector rotation for e-mbms transmission in lte systems. *JECE*, 2010:2:1–2:9, January 2010.