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A REAL – TIME ADAPTIVE ALGORITHM FOR VIDEO STREAMING OVER MULTIPLE ACCESS NETWORKS

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***Abstract*—In conventional wireless systems with layered architectures, the physical (PHY) layer equally treats all data streams from the upper layers and applies the same modulation and coding schemes to them. Newer systems such as Digital Video Broadcast start to introduce hierarchicalmodulation schemes with SuperPosition Coding (SPC) and support data streams of different priorities. However, SPC requires specialized hardware and has high complexity, which is not desirable for handheld devices. In this paper, we propose scalable modulation (s-mod) by reusing the current mainstream modulation schemes with software-based bit remapping. The performance evaluation has shown that s-mod can achieve the same and, in some cases, even better performance than SPC with much lower complexity. We further propose how to optimize the configuration of the PHY-layer s-mod and coding schemes to maximize the utility of video streaming with scalable video coding (SVC). Simulation results demonstrate substantial performance gains using s-mod and cross-layer optimization, indicating that s-mod and SVC are a good combination for video transmission in wireless networks.**

***Index Terms*—Scalablemodulation (s-mod) and coding, scalable video coding (SVC), SuperPosition Coding (SPC).**

I. INTRODUCTION

IDEO services are anticipated to be a major revenue generator for next-generation wireless networks. How to efficiently support video streaming over wireless networks is a key issue. In current wireless networks, the physical (PHY) layer mainly focuses on how to efficiently transmit information bits over the time-varying channel to approach the channel capacity. With the layered network architecture, the PHY layer treats every bit from the upper layer with the same priority and tries its best to reliably deliver each bit with the smallst possible bandwidth and lowest energy cost. However, for video applications, bits from the same flow may have different importance and impact on the user-perceived quality of service (QoS). For instance, scalable video coding (SVC) schemes may encode the video streams into a base layer and several enhancement layers, where the packet losses in the base layer lead to a much severer QoS degradation than those in the enhancement layers. Although differentiated services have been an active research topic in wireless networks, how to fine-tune the PHY layer, particularly the modulation scheme, to more efficiently support layered scalable video streaming remains an open issue. SuperPosition Coding (SPC) and its implementation (socalled hierarchical modulation or h-mod) have been considered as a promising candidate for video multicast. However, SPC (h-mod) requires more complicated hardware, and therefore, it is costly to be adopted in the current wireless mobile systems such as Third-Generation (3G)/Fourth-Generation (4G) and WiMAX. In addition, the cross-layer optimization, considering the configuration of the PHY-layer modulation and coding schemes, to maximize the utility of scalable video multicast beckons for more intensive research.

The s-mod schemes can be implemented using the existing quadrature amplitude modulation (QAM) modem. As a software-based approach, the s-mod schemes just redefine (or remap) the constellation points of the existing QAM to modulate and demodulate the layered bits with different bit error probabilities (or bit error rate, BER). Second, we formulate a cross-layer optimization problem, aiming to maximize the profit (which equals the utility minus the cost) of scalable video multicast and unicast, by optimizing the configuration of the PHY-layer s-mod and coding schemes. Finally, extensive simulations with real videos and realistic wireless channel profiles are conducted to evaluate the performance of different modulation schemes and demonstrate the advantage of the proposed cross-layer optimization framework and the s-mod schemes.

Video streaming over wireless networks is compelling for many applications, and an increasing number of systems are eing deployed. Video streaming of news and entertainment clips to mobile phones is now widely available. For urveillance applications, cameras can be _exibly and heaply installed, if a wireless network provides connectivity. A wireless local area network (WLAN) might connect various audiovisual entertainment devices in a home. Last, but not least, in search-and-rescue operations, real-time audiovisual communication over wireless ad-hoc networks can save ives. While video streaming requires a steady _ow of information and delivery of packets by a deadline, wireless radio networks have dif_culties to provide such a service reliably. The problem is challenging due to contention from other network nodes, as well as intermittent interference from external radio sources such as microwave ovens or cordless phones. For mobile nodes, multi-path fading and shadowing might further increase the variability in link capacities and transmission error rate. For such systems to deliver the best end-to-end performance, video coding, reliable transport and wireless resource allocation must be considered jointly, thus moving from the traditional layered system architecture to a cross-layer design.

II. STREAMING OVER A SINGLE WIRELESS LINK

As the wireless link quality varies, video transmission rate needs to be adapted accordingly. In [1], measurements of packet transmission delays at the MAC layer are used to select the optimal bit rate for video, subsequently enforced by a transcoder. The bene_t of cross-layer signalling has also been demonstrated in [2], where adaptive rate control at the MAC layer is applied in conjunction with adaptive rate control during live video encoding. Video rate adaptation can also been achieved by switching between multiple bitstreams encoded at different rates [3, 4], or truncating the bitstream from a scalably encoded representation [5]. Packets can also be dropped intelligently, based on their relative importance and urgency, utilizing the rate-distortion optimized framework introduced in [6]. The bene_t of cross-layer video rate adaptation is illustrated in Fig. 1. We simulate the transmission of a single video stream over an otherwise idle 802.11a wireless link. With a nominal link speed of 54 Mbps and a much slower transmission rate of 6 Mbps for MAC-layer headers and control packets, the effective maximal throughput is about 40 Mbps for video packets of 1500 bytes. The HD video sequence *Harbor* (1280x720p, 60 fps) is encoded using the H.264/AVC reference codec, with GOP length of 30 at various uality levels. Video streaming at one _xed quality level using TCP is compared against streaming on top of UDP with a video-aware application-layer transport protocol. The application-layer rate controller switches between different versions of video bitstreams according to estimated link capacity. While acknowledgment packets are sent for every received packet in TCP, the ACK frequency is reduced to once every ten received packets in the application-layer transport protocol. As a consequence, a higher video rate and quality can be supported, due to the reduction of acknowledgment overhead 1. Between time 8 and 12 seconds, the simulated Wireless link experiences 32% packet loss at the MAC layer, leading to many retransmissions and much lower link capacity. During this period, the transport rate of the TCP agent _uctuates over a wide range due to variations in the observed end-to-end packet round-trip-time. TCP congestion control defers transmission of incoming video packets until previous packets are acknowledged. This causes many packets to miss their playout deadline, even after the channel has recovered. When adaptation is allowed, the video bitstream is

III. PRELIMINARIES AND RELATED WORK

A. AMC

Wireless channels suffer from time-varying impairments due to user mobility, fading, shadowing, etc.; therefore, the received

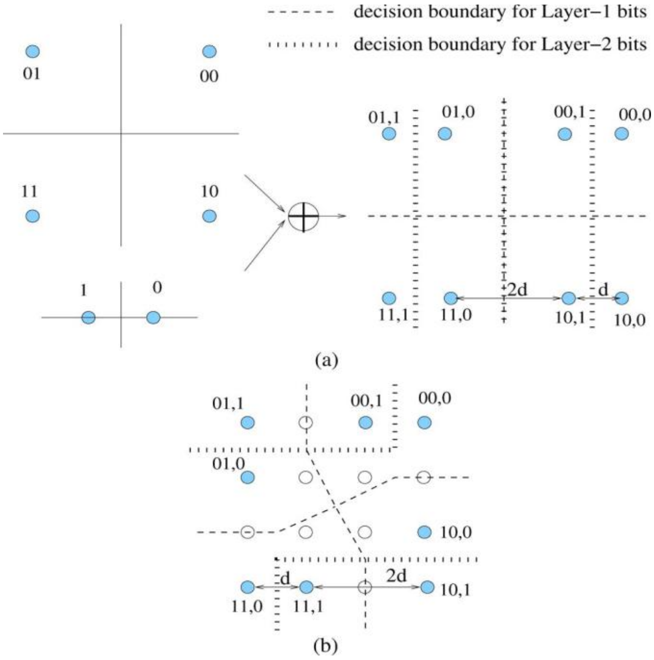

Fig. 1. S-mod versus SPC: an example. (a) SPC. (b) Scalable modulation.

signal-to-noise ratio (SNR) is changing. To maximize the application throughput with an acceptable BER, AMC schemes have been proposed and widely deployed in broadband wireless systems, e.g., the 3G/4G cellular systems [2] and WiMAX [3]. In short, instead of using fixed modulation and coding schemes, the receiver monitors the channel and predicts its condition. The receiver then feeds back the information to the transmitter, which will adjust the modulation and coding schemes accordingly for the next frame being transmitted. If the channel condition is relatively stable and the prediction is accurate,AMC can achieve high spectral efficiency on fading channels.

B. ***SPC and h-mod***

Although AMC is preferred for unicast transmissions, it is not suitable for multicast or broadcast transmissions. First, getting real-time feedback from multiple receivers is ontrivial. Second, different users have different channel conditions, and they may prefer different modulation and coding schemes from have been proposed [4]. The idea of h-mod (SPC) is to multiplex and modulate multiple layers of the data streams into a single symbol stream, where symbols for different layers are synchronously superimposed together before transmission [5]. For instance, as shown in the same transmitter from time to time. Consider the scenario that a base station (BS) multicasts to a group of receivers in the downlink. To ensure reliable transmissions of all bits to all receivers, the BS has to choose the modulation and coding schemes that meet the BER requirement of the receiver with the worst channel condition at any time. On the other hand, for scalable video streams, receivers can enjoy the services, even if only part of the data is successfully received. For these applications, h-mod schemes based on SPC have been proposed [4].

Fig. 1(a), instead of separately transmitting two bits per symbol with quadrature phase-shift keying (QPSK) and one bit per symbol with binary phase-shift keying (BPSK), the transmitter can superimpose the QPSK symbol with the BPSK symbol and transmit the resultant symbol with three bits of information. On the receiver side, it first demodulates the bits of QPSK (the layer with a larger Euclidean distance) and then uses interference cancellation to decode BPSK (the layer with a smaller Euclidean distance). Because the minimum Euclidean distances (MEDs) of QPSK (Layer-1) and BPSK (Layer-2) are $2d$ and d, respectively, for receivers with good channel quality, they may successfully demodulate the bits from both layers; for those with bad channel quality, they may demodulate the Layer-1 bits only.

From an information-theoretical perspective, SPC can achieve a higher maximum sum rate of a Gaussian broadcast channel than the time-sharing schemes [4] (i.e., separately modulating and transmitting bits of different layers). However, existing h-mod schemes require specialized hardware for interference cancellation, and they suffer from interlayer interference. Specifically, the demodulation process for h-mod requires either hard- or soft-decision-based interference cancellation, which requires additional hardware support [6], and it will lead to a higher complexity and cost. Therefore, although h-mod has been adopted in the Digital Video Broadcast-Terrestrial (DVB-T) standard, it is more difficult to be used in wireless networks due to the hardware and performance limits.

C. SVC

On the other hand, SVC [7] is an appealing coding technique for video/Internet Protocol television (IPTV) transmissions. It has been finalized as the ITU-T H.264 and ISO/IEC 14496-10 standards [8]. With a moderate increase in complexity and a slight decrease in efficiency, SVC provides spatial, temporal, and quality scalability. Sub-bitstreams with different types of scalability can be extracted from a single SVC-encoded bitstream. When different subsets of the bitstream are decoded, videos with different frame rates, resolutions, and quality can be reconstructed. This feature is naturally more efficient than simulcast or transcoding for heterogeneous network users. In particular, in a wireless multicast network, users can easily receive and decode the proper subbitstreams of an SVC bitstream due to the broadcast nature of wireless media. A layered structure is essential for SVC. For each type of scalability, there is one base layer and several enhancement layers. Since there is a correlation between the lower layer (the base layer or the initial enhancement layers) and the higher layer, SVC exploits the information of the lower layer as much as possible to reduce the number of bits needed for the higher layer. For quality scalability, SVC provides mediumand coarse-grained quality scalability (CGS). Taking the twolayer CGS as an example, a video stream is sampled into a sequence of frames, and a number of (I, B, P) frames comprise a group of pictures. Encoded bitstreams can be divided into two layers: the base layer can provide the minimum satisfactory video quality; with the enhancement layer, better video quality can be achieved. The reason SVC is more rate-distortion efficient than simulcast is that SVC utilizes interlayer prediction, which means that the information of the base layer is used to predict that of the enhancement layer; therefore, only the residual data of the enhancement layer and the base-layer prediction are encoded. However, when the base layer is corrupted or lost, the enhancement layer itself cannot improve the video quality or even decode the video bitstream. Because of the importance of the base layer, more protection should be added to the base layer. Therefore, when we choose modulation and coding schemes, it is desirable to provide different services for different layers.

D. Cross-Layer Optimization for Video Transmission in Wireless Networks

Resource allocation for supporting video transmission in wireless networks is a challenging issue, due to the timevarying wireless channels and the highly bursty video traffic. Given the wireless channel profile and video traffic model, we can use a fluid model to quantify the queue length distribution and packet loss rate, which can be used to determine the appropriate admission region for video/IPTV traffic [10]–[15]. In the literature, the theory of effective bandwidth and effective capacity has been proposed to obtain the probability of queuing delay exceeding a threshold, and thus, the statistical delay guarantee can be achieved for single-layer or layered video streams [16], [17]. These works mainly focused on the link layer and above, and did not consider how to manage the Hylayer modulation schemes to support layered videos. Recently, cross-layer optimization for multicast in wireless networks considering AMC began to attract attention. In 18]– [20], how to choose the right modulation and coding schemes to ensure efficient and reliable multicast was studied. How to optimize power allocation for SPC was proposed in [21];

IV. SCALABLE MODULATION

A. An Example

The main objective for scalable modulation is to efficiently provide differentiated services to different classes of information bits. To achieve service differentiation, we can construct the signal constellation of the modulation scheme such that the MEDs of the bits in different layers are different.

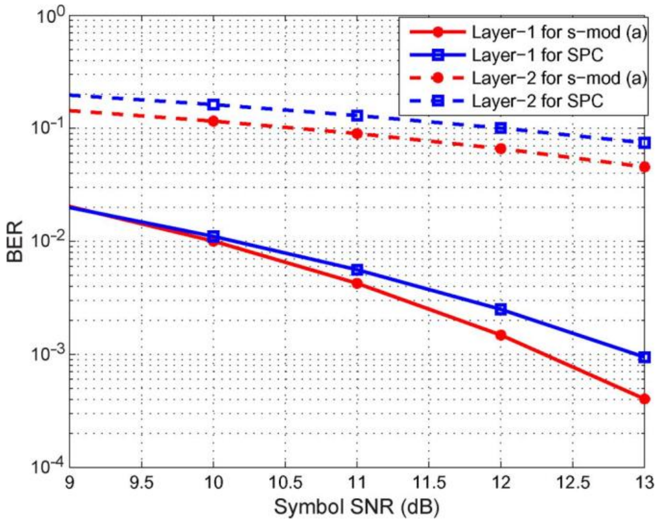

Fig. 2. BER comparison for s-mod and SPC.

Another design constraint for wireless mobile systems is the relatively simple transceiver design of handheld devices. Therefore, we aim to design the scalable modulation schemes based on the existing modulation hardware. As QAM schemes are typically supported in existing wireless systems, we can use a software-based approach to remap the constellations of the existing QAM modulation schemes to support differentiated services.

Fig. 1(b) gives an example of the proposed software-based s-mod scheme, which supports two layers of bits with the MED of 2*d* and *d* for layer-1 (L1), the high-priority layer, and layer- 2 (L2), the low-priority layer, respectively. The demodulation decision regions can be obtained by finding the Voronoi diagram of the signal space for each layer. The probability of each layer's bits being successfully demodulated equals the probability that the received symbol is within their decision region. *B. S-mod for Single-Layer Bits* The main idea of s-mod is to remap the constellation points of existing modulation schemes to the bits in different layers. With more constellation points, there will be more design space for s-mod. In the current wireless systems such as WiMAX, up to 64-QAM is typically supported. Thus, in the following, we use the constellation of 64-QAM as an example to illustrate the s-mod design. First, we investigate the case of transmitting single-layer bits using 64-QAM, where the MED of two adjacent constellation.

V. CONCLUSION

In this paper, we have proposed scalable modulation schemes that can provide differentiated services in the PHY layer using the current mainstream QAM modulation and demodulation hardware. We have further formulated a cross-layer optimization problem, aiming to maximize the profit of video services by selecting PHY-layer modulation and coding schemes. Extensive simulation results have demonstrated that, with the flexibility of s-mod, we can have better PHY-layer configurations to achieve substantial profit gains for wireless videocast. In this paper, if there is any bit error in a NAL unit, the NAL unit is discarded. The impact of other advanced error concealment strategies on the system performance with s-mod will be an important further research issue.

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