

UNIFIED FRAMEWORK OF SOURCE-CHANNEL-MODULATION CODING IN LOW POWER MULTIMEDIA WIRELESS COMMUNICATIONS

Tse-Hua Lan and Ahmed H. Tewfik
Dept. of Electrical and Computer Engineering
University of Minnesota, Minneapolis, MN 55455
E-mail: tsehua,tewfik@ee.umn.edu

Abstract - We study the problem of jointly optimizing source/channel/modulation coding to achieve a given quality of service while minimizing the total power consumption of mobiles. This paper emphasizes the design of a robust transmission framework in the context of total power minimization scheme. We design a simple but efficient transmission scheme which is called multistage coded modulation that combines source/channel (S/C) coding and multirate modulation (MM). We then integrate into this scheme a complexity-scalable video coder to achieve the best trade-offs in multimedia wireless communications between total power, quality of service, and capacity. Preliminary results show superior video frame quality (around 3dB better than the simple S/C coding scheme) of the proposed system in the severe channel condition, with total power consumption kept to a minimum.

INTRODUCTION

Successful Internet applications and cellular communications have generated many attempts to integrate multimedia applications and mobile communications. The authors have pointed out that one of the main challenges in this integration effort is the requirement of low power consumption of mobile units. In [1] we proposed a new design for wireless multimedia communications that minimizes total power consumption (processing power and transmission power) in mobiles. However, we used a conventional transmission scheme (channel coded modulation for power-limited system, and multilevel modulation for bandwidth-limited system) to accommodate multirate bit stream. Several rich data transmission approaches have been proposed in the literature. One class of techniques relies on joint source channel coding, i.e., the source coder is designed to adapt channel nature. In some approaches the quantizer is being optimized [3]. In others, the joint source/channel rate is optimized [4]. In the quantizer optimized coding the quantization step is redesigned according to channel condition. In the source/channel rate optimized coding the tradeoff between source coding rate and channel coding rate is set in an optimum way to fit into current channel state. Another class of techniques uses

a joint source modulation approach. For example, [5] optimizes the bit mapping from the encoded bit stream to the modulation constellation. Another joint source modulation approach is the multirate modulation [6]. It is similar to source/channel rate optimized coding, but instead of using channel coding, it uses lower level modulation to maintain the performance at severe channel condition.

The primary goal of the aforementioned methods is to keep the raw information bit error rate (BER) to a certain level. Figure 1 depicts roughly their performance. The result of their effort either through channel coding or modulation is to minimize transmission power in the presence of fading or path loss. This is the same goal as we proposed in [1, 2]. However the system in [1] differs from the above methods in two important respects. First, the total power consumption rather than just transmitter power is optimized. Second, the scheme guarantees a quality of service. In this paper we try to integrate source/channel/modulation coding in such a way that the combined scheme can be applied to previously proposed systems to render optimum system performance. Multiresolution modulation [7] seems to provide a nice integration of source/channel/modulation coding (figure 1, middle). However, the source coding algorithm must match the multiresolution structure. Source coders used in this approach are usually less efficient by design to be able to exploit an optimum mapping, or multiresolution structure. Current advanced multimedia coders do not preserve such structure after being efficiently coded or FEC protected (e.g., JPEG, MPEG). Figure 3 shows the point distribution in the QAM constellations. It can be seen that encoded bit stream does not exhibit any advantage for optimum source-constellation mapping either in the pre-channel coding case or channel coding case. Therefore, at this stage, we rule out the possibility of using source-modulation coding in our framework, unless we have a less compressed bit stream that satisfies either a multiresolution structure, or an optimum mapping criteria. On the other hand, S/C coding or MM does not work in the wide range of bit rates used in our system [1, 8]. And neither of them alone performs optimally in the BER measure. Another disadvantage of S/C coding is the compromised quality of information through the use of graceful degradation principle. This is due to the re-quantization effect of most of variable rate source coders used in conjunction to the channel coding. Figure 2 (left) shows the conventional criteria used in the wireless world. The right picture depicts our criteria for robust multimedia communications, in which the graceful degradation principle is replaced with a guaranteed quality of service paradigm. In summary, our work can be highlighted as follows:

1. Design of an optimized approach to combining multirate modulation and forward error correction (FEC) coding through the seamless integration of FEC coding and the inserted modulation, and exploitation of joint source-modulation scheme in the current state of the art coders,
2. Integration of the proposed communication framework with minimum total power multimedia wireless communication scheme to guarantee a higher quality of information at minimum power dissipation,

3. Study of the true resource trade-offs in modern multimedia wireless communications, in which the total power dissipation and guaranteed quality of service are paramount.

MULTISTAGE CODED MODULATION AND LOW POWER COMMUNICATIONS

We begin by establishing a flexible and efficient coded modulation framework. Let us start the performance analysis of FEC coding and multilevel modulation, with the intention of establishing a rule for the combined FEC and modulation. Figure 5 illustrates their behavior. The bottom figure shows the coding gain that results from using FEC over uncoded modulation. Notice that we pay a price: bandwidth expansion. The top figure provides better understanding of the performance under same bandwidth requirement. FEC coded modulation yields low power dissipation, but with a reduced information bit rate. We can see that coded modulation fails to render large E_b/N_o improvement at the high correction capability ($t > 5$). At the same information bit rate, we can see 4QAM outperforms coded 16QAM for BER greater than 10^{-7} . For most of multimedia data the source BER threshold is around 10^{-5} . If we have a complexity-scalable coder [2] and its data rate ranges from 0.6 to 1.8 bpp, then we can use combined FEC and QAM in a following way: information bit rate = 0.6, 0.7, 0.8, 0.9, 1.0, 1.2, 1.42, 1.62, 1.8 bpp (figure 5, top with "x"). We avoid using BCH(63,39,4) and BCH(63,30,6) codes, since they are not efficient. 4QAM without FEC coding is used in the 1.0 bpp case (not 16QAM+BCH(63,30,6)). Notice that neither of S/C or MM alone works well in our case.

Our design goal is to have a simple reconfigurable QAM scheme and FEC coding that guarantees a given quality while minimizing total power consumption. Minimum total power consumption is achieved by switching between possible modes of operations. To make the switch between higher level modulation and the lower level simple we introduce the so-called inserted MQAM. Figure 6 shows the constellation of a 16QAM. A 4QAM constellation can be accomplished under 16QAM constellation by adding two more bits '11' to the end of every two bits in a bit stream. Note that this switch between 4QAM and 16QAM practically does not increase complexity on both side of a transmission link. The inserted bits will be dropped at the receiver side. Figure 7 shows the operation of our system. In this work we just show the example of 4QAM and 16QAM switch, since they are suitable for wireless communications. Mode control mechanism can be either implemented at the mobile or at the base station [8]. The mode switching of conventional S/C coding is based on the peak power constraint, since we want to keep media quality as high as possible. See the power trajectory of figure 4. The conventional S/C coding tries to maintain a constant transmission power level with the degradation of quality at deep fade. Our proposed method with total power minimization scheme seeks minimum total power at each region of the normalized noise level.

PRELIMINARY RESULTS

We simulate video transmission in a wireless channel. In this example we assume that the mobile is under a slow fading and path loss effect. Figure 8 shows the tradeoff between efficient source coding and required processing power. This figure satisfies the inverse rate-complexity rule proposed by [1]. Readers can easily figure out that a variable-rate re-quantization coder has practically constant power-rate curve. Figure 9 illustrates total power curve in the multimode complexity-scalable H.263 video communication scheme. Here we use a modified H.263 video coding scheme to encode the QCIF Suzie sequence from Telenor [9]. The transmission system consists of our proposed multi-stage modulation scheme, with peak power limited to 250 mW (microcell). We assume the transmitter efficiency is around 50%. Conventional S/C coding (4QAM+BCH) is used in the simulation to make a comparison to our system. Figure 11 shows the results. We can see that our system outperforms the conventional S/C coding when normalized noise (fading, path loss, or interference) is severe (between 2-3.5 seconds). As far as total power is concerned, the average power dissipated by our system is around 620 mW, and 605 mW for the conventional system. In the bottom of figure 11 we can see that our system switches to the most efficient mode to compress video frames in the most adverse condition, since one can see the boost of power consumption (due to processing power). On the other hand, the conventional method maintains a near-constant power consumption in the simulation with a price of quality degradation. Figure 10 b) shows how badly the video frame got decoded at 2.5 second (frame 76). The blocking effect is due to the bigger step size of re-quantization process used in the S/C coding to accommodate low bit rate transmission. Our system shows superior quality (see figure 10 a) and look at the better detail on the facial expression), which is around 3db better than the conventional one.

SUMMARY

In this paper we proposed a unified framework for robust multimedia communications. In this framework one can communicate with others with guaranteed quality of information, and the mobile consumes minimum required power. Our proposed method successfully combined the advantage of source-channel coding and multirate modulation. The main difference between our framework and others is through the power control mechanism with the integration of S/C and multirate modulation and the total power minimization scheme. We no longer try to deliver multimedia data at degraded quality in the channel mismatch, but to guarantee high quality delivery, while minimizing total power consumption.

ACKNOWLEDGMENT

Special thanks to the Telenor group in Norway for the free source code and the video clip.

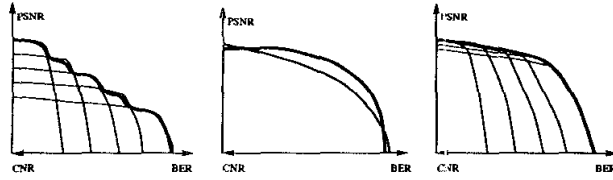


Figure 1: Comparison of various robust image transmission. Left: joint Source channel/modulation coding. Middle: joint source modulation coding (e.g., multiresolution modulation, constellation mapping etc.) Right: our proposed method.

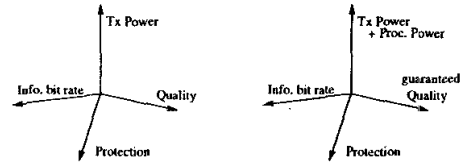


Figure 2: Resource tradeoffs diagram. Left: general case. Right: our case.

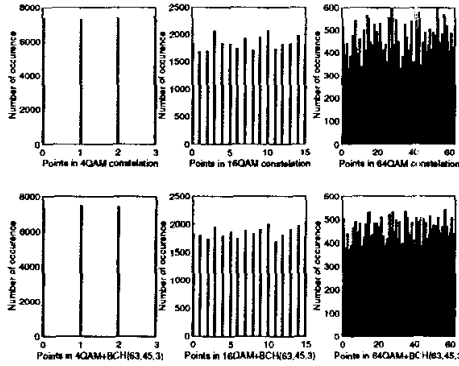


Figure 3: Point distribution in the QAM constellations using JPEG encoding and FEC.

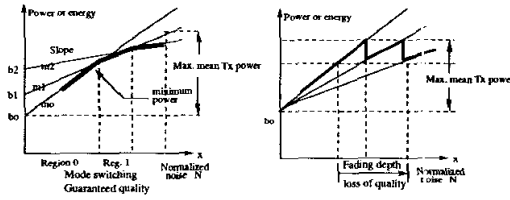


Figure 4: Left: Simplified total power curve. Right: Conventional power curve under fading. Bold line: power trajectory.

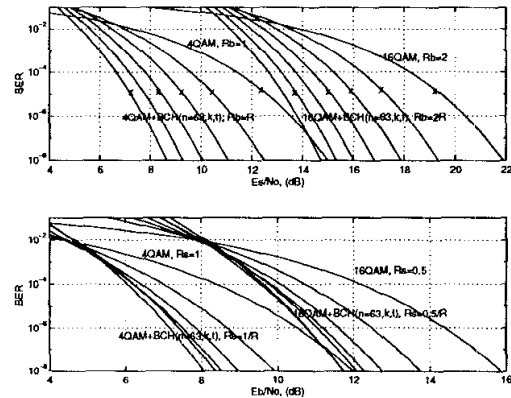


Figure 5: Coded and uncoded modulation. Top: BER vs. E_s/N_o , with same symbol rate (bandwidth), different information bit rate. Bottom: BER vs. E_b/N_o , with different symbol rate, but same information bit rate. For BCH coded curves: from right to left, $t=1, 2, 3, 4, 5, 6$. k : information bits, n : coded bits, $R=k/n$.

References

- [1] T.-H. Lan and A. Tewfik, "Adaptive Low Power Multimedia Wireless Communications," in *Proceedings of the IEEE Multimedia Workshop*, (Princeton), 1997.
- [2] T.-H. Lan and A. Tewfik, "Power Optimized Mode Selection for H.263 Video Coding and Wireless communications." Accepted for publication for ICIP98, Chicago, October 1998.
- [3] N. Farvardin, "A Study of Vector Quantization for Noisy Channels," *IEEE Transactions on Information Theory*, vol. 36, pp. 799–809, July 1990.
- [4] G. Cheung and A. Zakhor, "Joint Source/Channel Coding of Scalable Video over Noisy Channels," in *Proceedings of ICIP*, 1996.
- [5] I. Kozintsev and K. Ramchandran, "Multiresultion joint source-channel coding using embedded constellations for power-constrained time-varying channels," in *Proceedings of ICASSP96*, pp. 2345–2348, 1996.

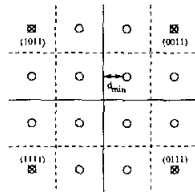


Figure 6: Signal constellation of the inserted 4QAM and the 16QAM

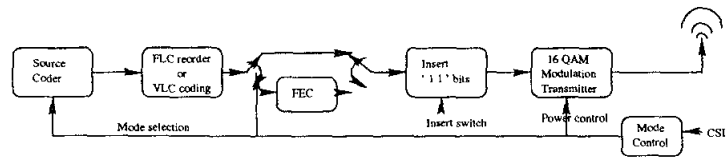


Figure 7: Proposed multistage coded modulation

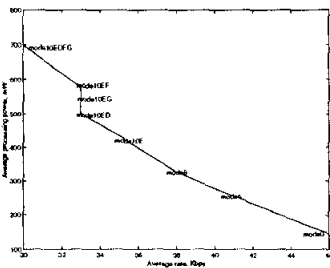


Figure 8: Processing power vs. coding rate

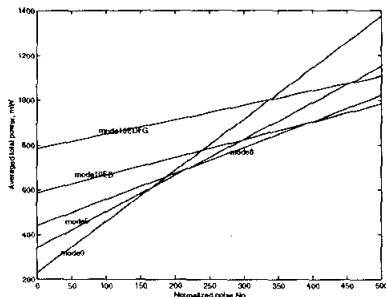


Figure 9: Multimode multi-stage total power curve

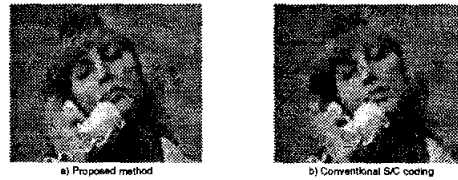


Figure 10: Video frame #76.

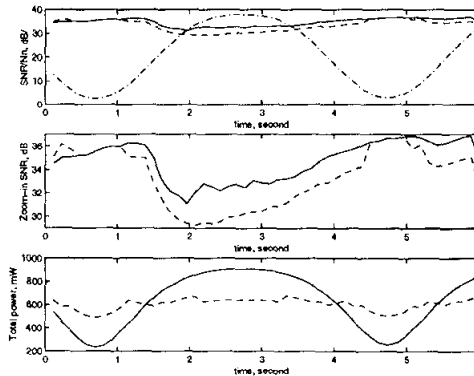


Figure 11: Simulation result under slow fading and path loss. Top: “-.”:normalized noise, solid line: SNR of our proposed method, disconnected line: SNR of conventional S/C coding. Middle: Zoom in version. Bottom: Total power consumption of both system.

[6] W. Webb and L. Hanzo, *Modern Quadrature Amplitude Modulation*. IEEE press, 1994.

[7] K. Ramchandran, K. M. U. A. Ortega, and M. Vetterli, “Multiresolution broadcast for digital HDTV using joint source/channel coding,” *IEEE Journal Select. Areas in Communications*, vol. 11, pp. 6–23, Jan. 1993.

[8] T.-H. Lan, “Adaptive Low Power Multimedia Wireless Communications.” Unpublished PhD. Proposal, September 1997.

[9] Telenor, “H.263 software simulation.” <http://www.nta.no/brukere/DVC>.