Poster Abstract: Polar Code-based Approximate Communication System for Multimedia Web Pages

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ABSTRACT

Polar codes have hitherto been used in the control plane of 5G-NR systems. However, in line with other contemporary works, we propose a novel use of them in the data plane by leveraging their natural property: different bit positions suffer from different degrees of errors. The idea is to map different components of web pages to different bit positions (based on their priority). We evaluate our approach for web page transmission over a wireless link that traditionally uses TCP and demonstrate benefits for image and video-based web pages. For an image-based web page, there is a 47.96% to 81.12% gain in performance, while the received image quality score varies between 0.97 and 0.99. We observe up to a 63.56% gain in performance for web pages with embedded videos with only a 7.45% loss in the received video quality.

1 INTRODUCTION

Polar codes are currently being used in the control plane of 5G-NR systems. There is extensive work underway to evaluate their feasibility in the data plane [10] in futuristic systems. We focus on an important property of polar codes that arises naturally from the underlying maths of channel polarization (not the case for the competing LDPC codes): different bit positions suffer from different degrees of errors. We map different parts of a typical HTTP transmission (over TCP) to different bit positions and show significant performance benefits with a minimal loss in the perceived quality.

There is some related work in this space. Du et al. [2] use polar codes for image transmission where the MSB bits are mapped to the more protected bit positions of the codeword. For LSB bit positions, we have the reverse case. Papers such as the one by Ransford et al. [5] use a different technique where they transmit the text data in a web page (including the HTML tags) via TCP and the image data using UDP. We combine both the approaches for polar codes to achieve the best of both worlds. This has not been done before to the best of our knowledge. We tolerate errors in the image/video part of a web page; we can either use UDP for them or use TCP (by recomputing the checksum at the base station). We evaluate the latter option in this paper even though our scheme is agnostic to the choice of the transport layer protocol.

Our specific contributions lie in simulating channels that use polar codes, characterizing the error across bit positions, and studying different bit mapping schemes. We show that we can significantly improve performance (50-80%) by reducing retransmissions if we are willing to tolerate some errors in lower bit positions. The quality score (experienced by humans) deteriorates very slowly until a certain point. We operate on the safer side of the knee of this curve.

2 PROPOSED APPROACH

A web page contains text data (HTML, CSS, javascript) that needs to be received without errors for the web page to load correctly and multimedia data (images, videos), which can be received with *bounded errors*. A web page loads the text data and images initially. Videos are downloaded separately if requested by the user.

2.1 Web Page

In the baseline method, the text data and the images are transmitted using separate codewords. We retransmit if any codeword is received in error to ensure 100% accuracy of both types of data. We propose a different approach. The text data is mapped to the more protected bit positions of the codeword, as it has high priority, and the image data is mapped to the less protected bit positions. We retransmit the message if there is an error in the text data part of the codeword, thus ensuring 100% accuracy of the text data. For the image data, we consider two different scenarios: (1) the message is not retransmitted even if there is an error in the image data part of the codeword, (2) the message is retransmitted if there is an error in the first k MSB bits of any image data pixel.

2.2 Video

The H.264 video encoding algorithm has a group of pictures (GOP) structure [11]. The first frame of the GOP is the I-frame, followed by P-frames. For good decoding accuracy of the video, the I-frame is of the highest priority. The importance of the P-frames keeps decreasing as we move further away from the I-frame [1]. We take advantage of this priority order. In the baseline video transmission method, all the frames in the GOP are equally protected using retransmission. We propose a different approach. We mix the data from the I-frame and the P-frames in a single codeword. The data from the I-frame is mapped to the most protected bit positions of the codeword. The data from the P-frames is mapped to the successive *most protected* bit positions in the order of their importance. The I-frame is always protected using retransmissions, and we vary the number of P-frames that are protected.

3 EVALUATION SETUP

Setup: We simulate our approach in Matlab R2021a. The data is encoded using a (512,1024) polar code and transmitted over an AWGN channel with an E_b/N_o value of 2 dB (similar to Ref. [2]). We also use the NetSim v12.0 [8] simulator to obtain the link delay. ***Metrics:*** The received image quality is measured using the MS-SSIM score [9]. The video quality score is the average of the MS-SSIM scores for all the image frames in the GOP [7]. Using Matlab simulations, we find the number of transmissions and retransmissions required to send the entire data. These are then fed into a popular TCP timing model [4] to determine the total time of transmission. The same model is used in [3] to estimate TCP throughput. The system's performance is defined as the reciprocal of the total time. We plot the performance gain of our approach compared to the baseline where we ensure 100% accuracy of all data types by retransmissions. ***Hyperparameters:*** For web page transmission, the ratio of the text data size to image data size is a hyperparameter. The performance of the system and the quality of the received image varies with this ratio (20:480 to 300:200). For the video, we consider the GOP has 14 P-frames and measure the performance and video quality score on varying the number of protected P-frames (0 to 14).

4 EXPERIMENTAL RESULTS

Using NetSim, we obtain a link delay of 1.38 ms for a 5G-NR network with E_b/N_o = 2 dB and single-hop distance = 190 m. We use it to compute the round-trip time and the retransmission timeout.

4.1 Web Page

We perform a design space exploration by varying the *ratio* hyperparameter. The results are presented in Figure 1. When no bit of the image data is protected (solid lines), there is an 81.12% gain in performance when the ratio is 20:480, with the image quality score being 0.97. As the ratio increases to 300:200, the quality score improves to more than 0.99, but the gain in performance decreases to 17.19%. When the first MSB bit of the image pixels is protected (dashed lines), the image quality score is more than 0.99 for all the ratio values. The performance gain is 47.96% when the ratio is 20:480 and decreases to 17.19.% when the ratio reaches 300:200. As the score is ≥ 0.99, we do not protect more bits of the image pixels. At a higher ratio value, more retransmissions are required to protect the text data, leading to a lesser performance improvement.

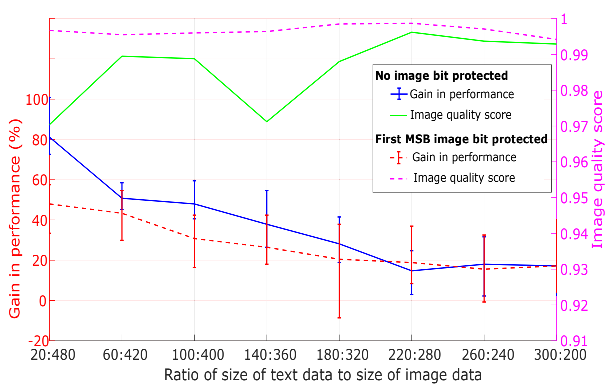

Figure 1: Gain in performance and the image quality score for different values of the text/image ratio (web page)

4.2 Video

The gain in performance and the video quality score are presented in Figure 2. We use the Big Buck Bunny video [6]. Even when all the P-frames are protected, the video quality score is 0.94 and not 1.00. This is because H.264 uses lossy compression. As the number of protected P-frames increases, the gain in performance decreases, and the video quality score improves. When no P-frame is protected, the gain in performance is 63.56%, and the quality score is 0.87. When 4 P-frames are protected, there is a 27.29% performance gain, and the quality score increases to 0.92. Most of the gains in video quality come from protecting 4 to 6 P-frames.

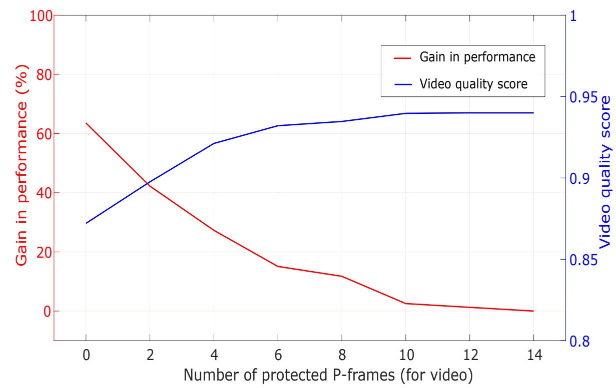

Figure 2: Gain in performance and the video quality score on varying the number of P-frames that are protected (video)

5 CONCLUSION

In this paper, we propose a multimedia web page transmission system for wireless networks. For image-based web pages, our system improves the performance by 81.12%. The performance gain for web pages with embedded videos is 63.56%, with only a 7.45% loss in the video quality score. This work has the potential to seed work that designs optimized application-layer protocols based on the idiosyncrasies of MAC-layer protocols such as polar codes.

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