

Energy Efficient Multiple Description Coding for Video Sensor Network

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Abstract— Video transmission over wireless sensor networks (WSN) is a very challenging research field. With sensor nodes operating on limited energy resource, computational power and network bandwidth, energy efficient coding and transmission are of extreme importance. As opposed to normal video systems, a video sensor network (VSN) system needs to provide high quality information only when the situation calls for it and only for part of the scene that is the region of interest (ROI). However, a certain degree of quality has to be guaranteed, especially for the ROI. In this paper, a simple technique based on multiple description coding (MDC) to reduce the amount of information transmitted while maintaining a higher quality for the ROI part of the frame is proposed. Experimental results show some significant gain in energy conservation as compared to the existing techniques.

Keywords—component; wireless sensor network, video sensor network, multiple descriptions coding, JPEG

I. INTRODUCTION

Recently, there is a growing interest in incorporating video applications and transmissions over wireless sensor networks (WSN) [1-4]. While visual sensing is not generally well-supported by WSN architectures, visual information may significantly improve the perceived information on the sensed environment. This is especially true for applications such as low-cost monitoring and surveillance systems [5-8]. Standard video coding techniques that are developed based on motion estimation algorithms are not suitable for sensor nodes [2, 9]. Instead, low complexity still image compression algorithms such as JPEG [10] are preferable. There are two commonly used techniques found in the literature. The first technique is based on Motion-JPEG where all frames are intra-frame coded. The second one is based on Wyner-Ziv coding [11], in which all key frames are intra-frame coded while the wyner-ziv frames are intra-coded and inter-frame decoded. Optimizing the efficiency of the intra-frame coding algorithm such as JPEG is very important since it is usually the one producing largest amount of data.

Since sensor nodes operate with limited resources, energy efficiency is the key issue in video sensor networks (VSN). Energy consumption can basically be divided into two categories: (i) energy spent for coding and (ii) energy

spent for transmitting the coded information. The algorithm for standard image coding such as JPEG is well known. Thus, energy footprint for JPEG-based technique can be estimated [12]. Since multimedia data contains redundancy in both spatial and temporal domains, a common energy saving techniques is based on reducing the amount of information processed, i.e., the number of transform coefficients. In the technique proposed in [12, 13], the quality of non-ROI part of the image is sacrificed by reducing the amount of discrete cosine transform (DCT) coefficients processed, while maintaining the quality of the ROI part.

Newer flash memory chips are much cheaper and efficient energy-wise in terms of write and erase operations and the associated energy cost are roughly two orders of magnitude less expensive than communication over the radio. This makes them ideal for archiving or caching video data at sensor nodes. Furthermore, while it is true that the quality of non-ROI parts of the image can be sacrificed, a certain amount of quality should still be guaranteed for these parts especially in a video surveillance system. This is because the data in the non-ROI parts may provide additional information related to the event of our interest, especially for evidence gathering and evaluation from video archive. Thus, a smarter data reduction and partitioning technique that can conserve more energy without losing relevant video information should be employed.

To ensure that the important part of the image is received with minimum error, the technique in [13] uses a reliable channel to send the ROI part of the image. However, providing a reliable channel in WSN is costly. Techniques that are commonly used to increase reliability such as forward error correction (FEC) and automated repeat request (ARQ) increase the data size, transmission delay or energy consumption. On the other hand, multiple transmission paths are naturally available in sensor network. This can be used to our advantage in terms of transmission reliability. In this regard, techniques that are based on multiple description coding (MDC) and path diversity have been widely examined for video transmissions over wired network [14, 15]. However, this approach has not been extensively studied for WSN.

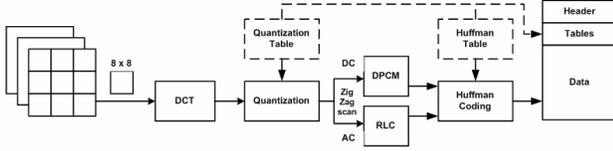


Figure 1. JPEG compression [10]

In this paper, the use of MDC to reduce the amount of information transmitted while maintaining a high quality for the ROI part of the image is studied. The proposed approach will be detailed in the next section. Experimental results and performance evaluation will be given before the concluding remarks.

II. THE PROPOSED APPROACH

JPEG is a commonly used method of lossy compression technique for still image. It has good enough compression rate that can be adjusted, allowing a trade-off between the compression rate and image quality. JPEG is a transform coding that utilizes discrete cosine transform. An image is divided into a number of 8x8 block pixels. These blocks will be transformed into frequency domain using DCT before quantization takes place. The top left DCT coefficient is called DC coefficient which is the low frequency response of the block. It represents the rough estimate image of the block. DC coefficient is large and varied, but its value is often close to the corresponding component in the previous block. Thus Differential Code Modulation (DPCM) is usually performed on them. The remaining coefficients are called AC components. It is encoded using Run Length Coding (RLC). Both the DPCM-coded DC components and RLC-coded AC components are then coded using Huffman coding. Fig. 1 shows the overview of JPEG compression technique.

The zig-zag scan orders the DCT coefficients based on DCT frequency response and its importance. A common technique to reduce the size of information processed, hence increasing compression rate, is by reducing the amount of AC coefficients considered for RLC and entropy coding. This can come in conjunction with using lower JPEG scaling parameter during quantization process. Note that, JPEG scaling parameter is inversely proportional with the quantization step. Thus smaller scale means larger quantization step, i.e., greater compression. However, this has an undesirable effect of reduction in the quality of image received by BS.

Triangular-JPEG (T-JPEG) is an adaptation version of JPEG by processing only the upper-left triangular portion, whose side's length is ρ , of each block of $k \times k$ DCT coefficients [12]. In this technique, the number of processed coefficient (C_p) is calculated as

$$C_p = \rho(\rho+1) / 2, \quad (1)$$

where $\rho \leq k$. Fig. 2 shows the portion corresponding to $\rho = 6$. Using this approach, the number of basic operations needed at each compression stage and the corresponding energy

dissipated will be reduced. If ρ increases, both the quality of the received image and the energy consumed by sensor nodes increase.

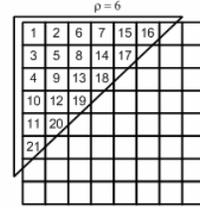


Figure 2. T-JPEG selection of AC coefficient ($\rho = 6$) [12]

Each frame is then divided into a number of sub-images based on its importance. By selecting different values of ρ for different parts of the frame, certain image quality can be guaranteed for each of the sub-image. Certainly, the ROI-part of the frame should have higher ρ value than the other parts of the frame. Unfortunately, since ρ cannot be greater than k , we cannot expect to have the highest quality image even for the ROI part(s).

On the contrary, in this paper, such limitation does not exist. The important part(s) of the frame can use as many DCT coefficients as needed to guarantee the best quality of reconstructed image in that part. The number of DCT coefficients considered for this part is denoted as *High Coefficient Count (HCC)*. The value of HCC can be determined by the user or administrator. On the other hand, *Low Coefficient Count (LCC)* represents the number of DCT coefficients used for the non-important part of the frame, and calculated as follow,

$$LCC = HCC / 2^{CRF}. \quad (2)$$

CRF is coefficient reduction factor, $1 \leq CRF \leq \log_2 HCC$, and is used as system's parameter.

The logic behind (2) is twofold:

1. It is not difficult to find out and/or determine the ratio of LCC to HCC . This may benefit the user operating the system.
2. Computation of LCC can be implemented in a very simple manner; using only shift register, i.e., $LCC = HCC \gg CRF$ (here \gg indicates right shift register).

It is clear that computation of (2) will be much simpler if HCC value is a power of two. It is also possible to have more than one LCC values. However, in this paper, for simplicity reason, we only consider one LCC value. It can be easily deduced that the gain in energy dissipation of the proposed approach is due to the fact that the number of DCT coefficients processed and transmitted is lower than the standard JPEG compression algorithm.

Furthermore, since multimedia data contains spatial and temporal redundancy, missing pixels information in a frame can be usually approximated by interpolating neighboring pixels. MDC exploited this fact by dividing multimedia data into a number of streams. In the simplest form, an image frame can be divided into two descriptions that have either the odd or even column of the original frame. These descriptions will be coded and transmitted independently.

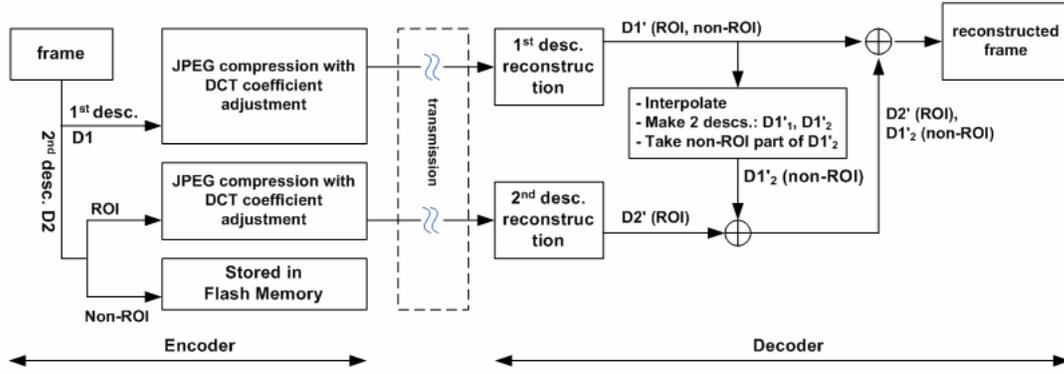


Figure 2. Encoder and decoder block diagram of the proposed approach

Upon receiving any of the descriptions, receiver can generate a lower quality of reconstructed data. Higher quality of information can be reconstructed if the two descriptions are received. In fact, if the two descriptions are received, receiver will have two versions of reconstructed frame. These can be used for error concealment of pixels that are missing due to packet losses. This in turn will increase the reliability of the system.

Based on the above observation, a simple technique using MDC is proposed. The technique is based on the idea that both descriptions of the ROI part of the frame will be processed and transmitted; however, only one of the description, i.e., the 1st description, of the non-ROI part that will be considered for processing. If the system is used for archival purpose, it is further assumed that each sensor has a flash memory attached to it.

The encoder part of the system proceeds as follow:

1. Divide a frame into two descriptions: D1 and D2.
2. For the 1st description (D1), JPEG encode the ROI part of the frame using *HCC* as parameter and non-ROI part using *LCC*, respectively.
3. For the 2nd description (D2), JPEG encode the ROI part of the frame using *HCC* as parameter. The non-ROI part will be stored in a flash memory.
4. Send both the encoded data to receiver.

On the receiver end, the following decoding procedure will be performed:

1. Decode the received 1st description, D1'.
2. Interpolate the reconstructed 1st description to generate a low quality version of the frame.
3. Divide the frame obtained from step 2 into two descriptions: D1'₁, D1'₂. Take the non-ROI part of D1'₂.
4. Decode the received 2nd description, D2'(ROI).
5. Merge the non-ROI part of D1'₂ obtained from step 3 with the decoded ROI part of D2' obtained from step 4. Hence $D2' \leftarrow D2'(ROI) + D1'_{2}(non-ROI)$.
6. Merge the D1' description obtained from step 1 with the D2' description obtained from step 5.

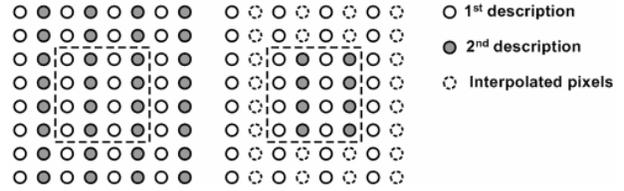


Figure 3. Illustration of the proposed approach: (a) at the encoder (b) at the decoder

The block diagram of the proposed approach is shown in Fig. 3. It is clear the ROI part of the reconstructed frame is obtained from both descriptions sent by encoder. However, only half of those in the non-ROI part are received. The remaining ones are interpolated to get an approximated version of the frame. It is clear that the ROI part will have higher quality than the non-ROI part. Fig.4 illustrates the concept of these procedures. In this figure, the pixels inside the rectangle with dash line are the ROI part.

The 2nd description of non-ROI parts that are stored in flash memory of sensor nodes can be used as archive or back up. When a user wants to have better quality image or if the received 1st descriptions of non-ROI parts contains too much error, the information in the flash memory can be sent to receiver. It should be noted that, this information is not similar to the ones sent before. Thus, no redundancy is added to the system.

III. PERFORMANCE EVALUATION

The proposed algorithm is implemented using Matlab. We want to study the effect of varying *CRF* values to the performance metrics mentioned below. Unless it is clearly mentioned, it is assumed that *HCC* is set equal to 64 and JPEG compression with medium quality, i.e., scaling factor is equal to 4. There are some performance metrics that we want to evaluate:

1. Coding efficiency in terms of complexity and compression rate
2. Image quality both in terms peak signal-to-noise ratio (PSNR) and visual look.
3. Energy efficiency for different frame transmission scenarios.

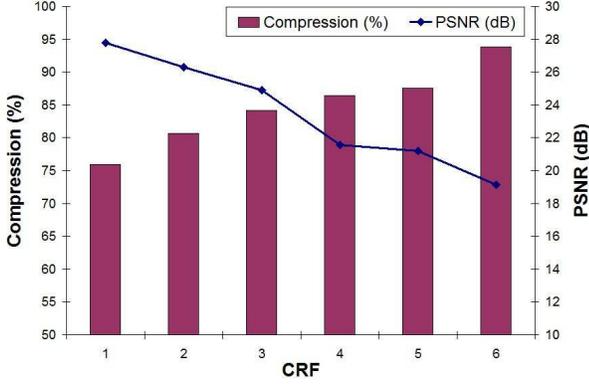


Figure 4. Compression rate and PSNR of PM-JPEG for $1 \leq CRF \leq 6$

In order to simplify the analysis, the following notations are used:

1. The proposed algorithm is called Partial MDC JPEG. The notation PM-JPEG(2) means the proposed algorithm with CRF equal to 2.
2. We performed a minor modification to the algorithm in [12] so that the ROI part uses the value of HCC as the number of DCT coefficients considered for processing: Modified Triangular JPEG. MT-JPEG(3) denotes the modified T-JPEG with ROI parts using the given HCC value as the number of DCT coefficients considered while non-ROI parts will use C_p (computed as in (2)) with $\rho = 3$, respectively.
3. JPEG(32) means standard JPEG with 32 DCT coefficients.

We consider a very simple network model where we only have one transmitter and one receiver. The power consumption model for the radio is similar to the one proposed in [16]. The total energy consumed for transmitting 1 bit of data between two nodes is:

$$e_b = e_{Tx} + e_{Rx} \quad (3)$$

In this equation, the energy dissipated by a given node to transmit one bit of data is calculated as $e_{Tx} = e_e + e_a d^\alpha$. The consumed energy in reception per bit is $e_{Rx} = e_e$. Where e_a is the energy consumed by the transmit amplifier per bit over distance of 1 meter, e_e is the energy dissipated by the transmitter electronics per bit, d is the line of sight distance between the transmitter and receiver and α is path loss exponent. The values of these parameters are: $e_a = 1.10^{-10}$ Joule/bit/m², $e_e = 5.10^{-8}$ Joule/bit, $\alpha = 4$, and $d = 5$ meters.

Fig. 5 shows the performance of PM-JPEG with different values of CRF for standard 256×256 pixels Lena image. The ROI part is 64×64 pixels covering Lena's face. Compression rate increases from 76% to 94% with the increase of CRF . However the overall PSNR of the image decreases with the increase of CRF . The PSNR of the ROI part however, is 37.7 dB for any CRF values.

In terms of encoding complexity, both descriptions are compressed using JPEG with DCT coefficient adjustment.

Since there is no additional redundancy, i.e., the number of pixels in each description is half of that in the original image, the overall complexity of the proposed algorithm should not differ too much with the standard JPEG. The overhead may come in the process of creating the two descriptions. In the standard JPEG, blocks of 8×8 pixels are processed sequentially. On the other hand, in the proposed algorithm, a block of 8×16 pixels are first read, and then divided into two 8×8 block of pixels. A larger buffer is then required to store these two blocks of pixels. This in addition to the extra instructions that may be needed to classify which description a column (row) belongs to. However, if the captured image's data can be accessed per column (row) basis, the overhead in creating the two descriptions can be minimized.

Since energy dissipation for encoding depends on the number of DCT coefficients processed, we used this parameter to quantify the gain obtained by the proposed algorithm. Furthermore, since both PM-JPEG and MT-JPEG reduce the amount of pixels sent, it is clear that PSNR for the received image will be lower than the one produced by standard JPEG. Table 1 gives the comparison of PM-JPEG with other techniques that give $24 \text{ dB} \leq \text{PSNR} \leq 29$, except for JPEG(64) that is used as benchmark. As can be seen clearly, both PM-JPEG and MT-JPEG present significant gain in terms of the number of coefficients processed and compression rate. It should be noted that having lower coefficient count does not reflect higher compression rate because coefficient count does not represent the size of the coefficients.

It is interesting to see that for almost similar PSNR value, PM-JPEG offers better compression rate than MT-JPEG. This is due to the reduction of 2nd description of non-ROI part. For example, PM-JPEG(2) uses 7857 coefficients with 80.65% compression rate to achieve 26.28 dB PSNR. However, MT-JPEG(3) uses 7668 coefficients with 74.99% compression rate to achieve 26.37 dB PSNR. Fig. 6 compares the two algorithms in terms of visual quality. It can be seen here that the proposed algorithm produce subjectively better visual quality than MT-JPEG. It should be noted that the PSNR of both MT-JPEG and standard JPEG is equal to 38.7 dB, while it is 37.7 for PM-JPEG. The reason behind this loss is because MDC introduces additional distortion by separating continuous signal into different blocks. The loss caused by MDC is relatively small if we encode the image to get the highest quality, i.e., using higher JPEG scaling parameter.

TABLE 1. COMPARISON OF PM-JPEG WITH OTHER TECHNIQUES

algorithm	Coeff. Count	Compr. (%)	PSNR (dB)	Gain Coeff. Count (%) *	Gain Compr. (%) *
JPEG (64)	21704	56.09	38.77	N/A	N/A
MT-JPEG (4)	10629	71.52	28.21	51.03	27.51
MT-JPEG (3)	7668	74.99	26.37	64.67	33.70
MT-JPEG (2)	5199	77.47	24	76.05	38.12
PM-JPEG (1)	11156	75.88	27.76	48.60	35.28
PM-JPEG (2)	7857	80.65	26.28	63.80	43.79
PM-JPEG (3)	5162	84.14	24.89	76.22	50.01

(*) Computes against JPEG(64)



(a)



(b)

Figure 5. Visual comparison of lena image from: (a) PM-JPEG(2): PSNR=26.28 dB, compression=80.65% and (b) MT-JPEG(3): PSNR=26.37 dB, compression=74.99%. For both image, $HCC=64$.

TABLE 2. FRAME TRANSMISSION SCENARIO

Scenario	Frame ID										PFD
	1	2	3	4	5	6	7	8	9	10	
Scenario 1	F	P	P	P	P	P	P	P	P	P	0.1
Scenario 2	F	P	P	P	P	F	P	P	P	P	0.2
Scenario 3	F	P	P	P	F	P	P	P	F	P	0.3
Scenario 4	F	P	P	F	P	P	F	P	P	F	0.4
Scenario 5	F	P	F	P	F	P	F	P	F	P	0.5
Scenario 6	F	F	P	P	F	F	P	P	F	F	0.6
Scenario 7	F	F	P	F	F	P	F	F	P	F	0.7
Scenario 8	F	F	F	F	P	F	F	F	F	P	0.8
Scenario 9	F	F	F	F	F	F	F	F	F	P	0.9
Scenario 10	F	F	F	F	F	F	F	F	F	F	1

It should be noted that the PSNR of both MT-JPEG and standard JPEG is equal to 38.7 dB, while it is 37.7 for PM-JPEG. The reason behind this loss is because MDC introduces additional distortion by separating continuous signal into different blocks. The loss caused by MDC is relatively small if we encode the image to get the highest quality, i.e., using higher JPEG scaling parameter.

As mentioned earlier in this paper, we believe that VSN system needs to provide high quality information only when situation calls for it. For most of the time, the system should try to conserve energy as much as it can, i.e., by using the proposed PM-JPEG algorithm. However, the system has to deliver higher visual quality should the user request for it. In order to evaluate the performance of our algorithm, we need to know the probability to send higher quality frame within a time period. For this purpose, we devise some scenarios that may be applicable for our system (see Table 2). In this table, in a span of 10 frames, each scenario represents a sequence of the type of frame quality requested by user. In this regard, ‘F’ indicates full descriptions, i.e., higher quality; while ‘P’ indicates partial descriptions, i.e., using PM-JPEG. As can be seen from the table, the scenario is selected so that each has different probability to send full descriptions (PFD). It is clear that the table does not represent all possible scenarios. However, using this simple table we can evaluate the performance of the proposed technique.

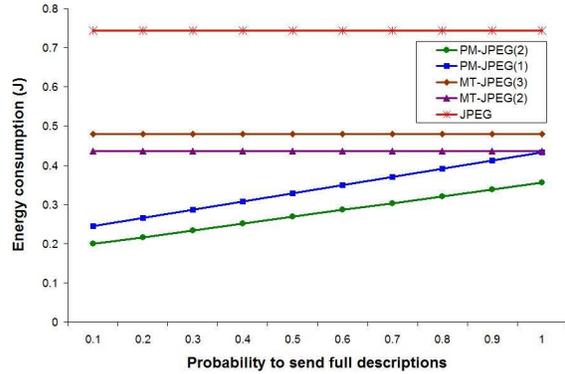


Figure 6. Performance of the proposed algorithm for different PFD

To evaluate these scenarios, we use test video 15 fps CIF Foreman. The ROI part of the frame is kept at the same location for all frames, which is 102×102 pixels around the foreman’s face. HCC is set equal to 32. Equation (3) is used to compute the energy consumption for each scenario. Fig. 7 illustrates the results for the first 10 frames. Note that, PFD is used only for the proposed PM-JPEG algorithm. Standard JPEG and MT-JPEG do not have any capability to send partial or reduced quality of image. This is the reason why both algorithms have constant energy consumption for all scenarios. It is shown clearly here that the proposed algorithm offers significant reduction for up to 50% in energy consumption to transmit the video data as compared to the standard JPEG.

Average PSNR for all scenarios is shown in Table 3. As can be expected, PSNR will increase with the increase of PFD . The variation of PSNR for all PFD is relatively small, calculated as 0.032 dB for PM-JPEG(2) and 0.035 dB for PM-JPEG(1). We believe that one of the reasons for this result is that the non-ROI parts of all those frames do not contain much information. In addition to that, the non-ROI parts of all those frames do not change a lot within the time period examined. Further examination with different test image and/or scenario is required to get a deeper analysis. We intend to do this in the near future.

TABLE 3. AVERAGE PSNR FOR DIFFERENT PFD

PFD	Average PSNR	
	PM-JPEG(2)	PM-JPEG(1)
0.1	27.34	29.631
0.2	27.359	29.693
0.3	27.378	29.755
0.4	27.396	29.817
0.5	27.416	29.88
0.6	27.435	29.942
0.7	27.453	30.006
0.8	27.473	30.067
0.9	27.491	30.129
1	27.51	30.191

TABLE 4. PSNR COMPARISON

Algorithm	Average PSNR (dB)	
	All	ROI part
PM-JPEG(1)	29.88	38.13
PM-JPEG(2)	27.42	38.13
MT-JPEG(2)	26.02	40.62
MT-JPEG(3)	28.59	40.62

Table 4 shows the comparison of average PSNR of the PM-JPEG with MT-JPEG. In this table, *PFD* is equal to 0.5. For overall PSNR, PM-JPEG is 1~2 dB PSNR better than MT-JPEG. This is at the cost of 2.5 dB lower in ROI parts of the frame. However, PM-JPEG uses 0.15~0.2 J less energy than MT-JPEG.

IV. CONCLUDING REMARKS

A simple approach based on coefficient reduction and MDC technique for energy efficient video transmission in WSN has been proposed. The proposed algorithm exploits the ability of MDC to generate lower quality image of the non-ROI parts of the frame while maintaining a higher quality image in ROI. The technique shows significant reduction in encoding complexity in terms of the number of coefficients processed. This is in addition to gain in compression rate. Although the proposed algorithm suffers some loss in terms of PSNR of ROI part due to MDC, the visual quality of the proposed algorithm is subjectively better than the existing techniques. Different scenarios of frame quality transmission in terms of PFD have been explored in order to exploit the energy saving capability of the proposed algorithm. Results show that with 50% probability of full description, 0.15~0.2 J of energy can be saved from transmitting the first 10 frames of the test image. To improve PSNR of the ROI part, the JPEG quality scaling factor for this part can be set to be higher than the rest of the frame.

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