Adaptive Image Compression for Wireless Multimedia Communication*

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Abstract — **To enable ubiquitous wireless multimedia communication, the bottlenecks to communicating multimedia data over wireless channels must be addressed. Two significant bottlenecks which need to be overcome are the bandwidth and energy consumption requirements for mobile multimedia communication. In this paper, we address the bandwidth and energy dissipation bottlenecks by adapting image compression parameters to current communication conditions and constraints. We focus on the JPEG image compression algorithm, and present the results of varying some image compression parameters on energy dissipation, bandwidth required, and quality of image received. We present a methodology for selecting the JPEG image compression parameters in order to minimize energy consumption while meeting latency, bandwidth, and quality of image constraints.**

I. Introduction

With the introduction of 3G wireless communication systems, together with the phenomenal growth and popularity of the internet, wireless multimedia communication is predicted to grow rapidly in the near future. For example, Fig. 1 shows how the predicted amount of wireless data transmitted due to multimedia content will increase much more rapidly than the amount of data transmitted for voice.

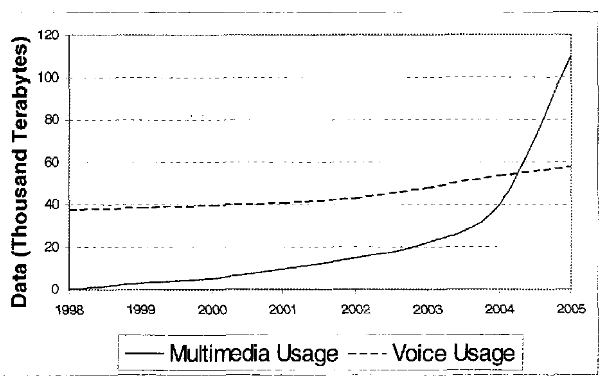

Fig. 1. Type of data transmitted over internet(source Analysys Ltd.)

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However, representing multimedia data requires a large amount of information, leading to high bandwidth, computation energy (energy consumed in processing information to be transmitted), and communication energy (energy consumed in wirelessly transmitting information) requirements for mobile multimedia communication. The large requirements for bandwidth and energy consumption are significant bottlenecks to wireless multimedia communication.

A characteristic of wireless multimedia communication which can be used to overcome the bandwidth and energy bottlenecks is that the conditions and requirements for mobile communication vary. Variations in wireless channel conditions may be due to user mobility, changing terrain, etc. For example, in [1], the Signal to Interference Ratio (SIR) for cellular phones was found to vary by as much as 100dB for different distances from the base-station.

Moreover, the Quality of Service (QoS) – such as transmission latency or bit error rate (BER) – and Quality of Multimedia Data (QoMD) – including image/video quality – required during multimedia communication changes depending on the current multimedia service. For example, the QoS (latency) and QoMD requirements of transmitted data are different between video telephony and web browsing.

One way to design a multimedia capable radio which accounts for varying communication conditions and requirements is to assume the worst-case. However, by designing a radio which adapts to current communication conditions and requirements, it is possible to help overcome the bandwidth and energy bottlenecks to wireless multimedia communication. For example, in [2], the authors adapt the channel coding parameters used to match current channel conditions, thereby increasing the average bandwidth available. An algorithm to modify the broadcast power of a power amplifier to meet QoMD requirements, thereby lowering energy consumption is proposed in [3]. In [4], the authors change channel coder and power amplifier settings according to current conditions in order to lower energy consumption.

While previous research has studied the effects of adapting the channel coder and power amplifier to current communication conditions and requirements, the effects of modifying the source coder have not been previously studied. In this paper, we focus on a commonly used source coding technique: the JPEG image compression algorithm. We study the effects of

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varying parameters of the JPEG image compression algorithm on energy consumption, bandwidth, and latency. We also introduce a methodology to select the optimal image compression parameters to minimize energy consumption given the current conditions and constraints.

The paper is organized as follows. Section II presents how changing certain JPEG image compression parameters affects the energy, latency, and image quality in wireless multimedia communication. Section III presents a methodology for run-time selection of image compression parameters in order to minimize the energy consumption of a multimedia capable radio given the current broadcast power, latency, and image quality constraints of the communication. We also present the energy savings possible through adaptive image compression. Section IV concludes the paper.

II. Effects of Varying JPEG Image Compression Parameters on Energy, Latency, and Image Quality

One of the issues that makes wireless multimedia communication difficult is the large amount of data that needs to be transmitted wirelessly. However, multimedia data can be compressed in a lossy (as opposed to lossless) manner, leading to smaller compressed representations of the multimedia data than is available with lossless data compression. Therefore, source coding (compression) plays an important role in communicating multimedia information.

The flexibility enabled by lossy compression can be exploited to enable tradeoffs in mobile multimedia radios. Tradeoffs between the Quality of Multimedia Data (QoMD) transmitted, the bandwidth required for communication, the energy consumed, and Quality of Service (latency) required in wireless multimedia communication are possible. In this section, we present the results of varying the parameters of JPEG, the most common image compression algorithm.

Fig. 2 shows a basic flow diagram of the JPEG image compression algorithm. To implement JPEG, the input image is divided into blocks of size 8 pixels by 8 pixels. Each of these 8x8 pixel blocks is transformed by a Discrete Cosine Transform (DCT) into its frequency domain equivalent. After the transform stage, each frequency component is quantized (divided by a certain value) to reduce the amount of information which needs to be transmitted. These quantized values are then encoded using a Huffman encoding-based technique to reduce the size of the image representation.

To investigate the effects of image compression parameters on energy, latency, quality of image, and bandwidth, we chose two parameters of the JPEG image compression algorithm to vary. The first parameter we chose is the scaling of the quantization values used in the quantization step of JPEG. The JPEG standard defines some default quantization tables which can be scaled up or down depending on the desired quality of the final

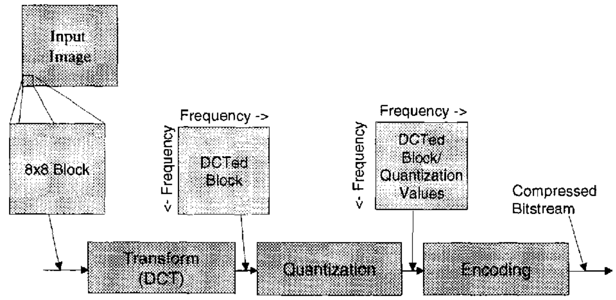

Fig. 2. Basic flow of JPEG image compression algorithm

image. As the quantization level decreases, the image quality increases, but more information needs to be transmitted, causing more bits to be transmitted.

The second parameter which we study is Virtual Block Size (VBS). This parameter affects the DCT portion of JPEG as first introduced in [5]. To implement VBS, the DCT still inputs the entire 8x8 block of pixels, but outputs a VBSxVBS amount of frequency information rather than an 8x8 block. Fig. 3 shows an example of setting the VBS to 8 and 5. When the block size is 8, all frequency information is computed. When the block size is 5, all frequency data outside the 5x5 block is set to 0. By setting the frequency values outside the VBSxVBS block to zero, less computation energy is required because the elements set to zero do not have to be computed or quantized. In addition, due to the encoding stage of JPEG, zeros require less bits to transmit, lowering the communication energy as the VBS values decrease.

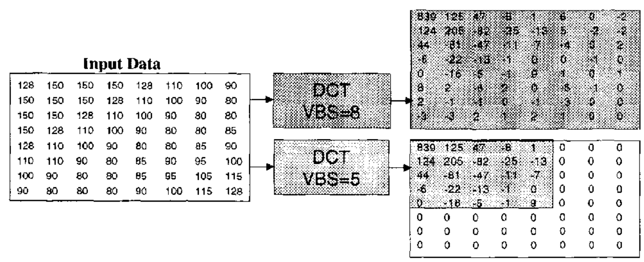

Fig. 3. DCT of input data with virtual block sizes 8 and 5

In the subsections that follow, we discuss the effect of varying the selected parameters (quantization level and VBS) on energy, latency, image quality, and bandwidth. We conducted our experiments using the Independent JPEG Group's C code [6] modified to implement VBS. All numbers presented are an average across four different images (monarch, peppers, sail, and tulips [7]). Image quality is represented by Peak Signal to Noise Ratio (PSNR), while computation energy is estimated by the number of operations needed to compress an image. We also assume that communication energy and latency is directly proportional to the number of bits transmitted. The communication energy per bit is determined by the power amplifier, independent of the image compression algorithm and parameters.

A. *Effects of Varying Quantization Level*

Varying the quantization level of the JPEG image compression algorithm has several effects on wireless multimedia communication. First, increasing the quantization level reduces the image quality. Increasing the quantization level also decreases the number of bits to be sent, decreasing the communication energy, latency, and bandwidth required to wirelessly transmit the image. Fig. 4 illustrates how increasing the quantization level leads to a decrease in the image quality (PSNR) and number of bits transmitted. The quantization values are linearly interpolated between quantization levels 0, 50, and 100, as defined by the IJG [6] (where 0 is no quantization and 100 is maximum quantization). The number of bits transmitted are normalized against transmitting with no quantization. All values assume a VBS of 8.

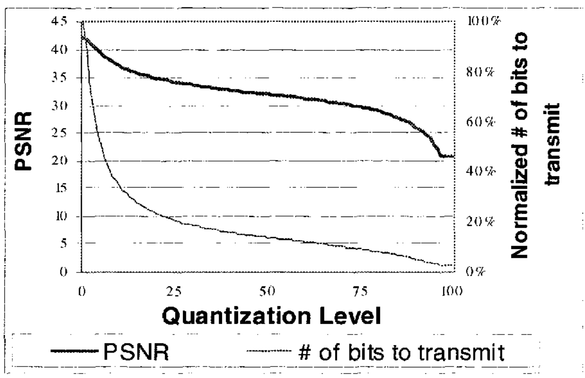

Fig. 4. Effect of varying the quantization level on image quality and number of bits required (communication energy, latency, and bandwidth)

B. *Effects of Varying Virtual Block Size*

As mentioned previously, the effect of Virtual Block Size (VBS) on computation energy and image quality has been studied previously [5]. In this subsection, we present the effects of choosing different VBS parameters on the communication (communication energy, latency, and bandwidth) of image data, as well as the effects on computation.

As smaller VBSs are chosen, the quality of image and computation energy used in the DCT and quantization portion of the JPEG algorithm decrease, while the energy consumed in the encoding portion remains the same. In addition, because zeros require fewer bits to encode, the number of bits transmitted, and therefore the corresponding communication energy, latency, and bandwidth required, also decrease. In Fig. 5 we show the decrease in image quality, computation energy, and number of bits transmitted caused by decreasing the VBS. The computation energy and number of bits transmitted values are normalized for when the VBS is 8.

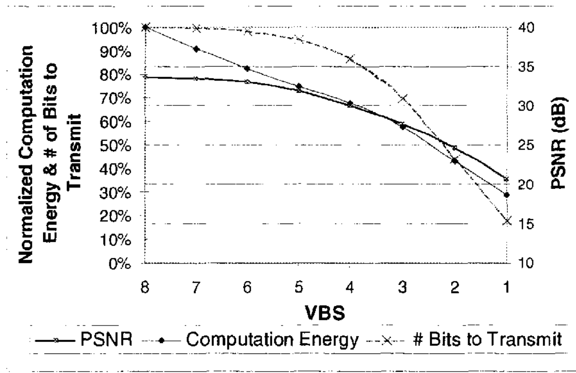

Fig. 5. Effect of varying the virtual block size on image quality, computation energy, and number of bits transmitted

Knowing the results of varying quantization levels and VBS permits an intelligent selection of image compression parameters to enable wireless multimedia communication. In the following section, we present a methodology which uses knowledge of image compression parameter effects to lower the energy consumption of a multimedia capable radio, helping to overcome the energy consumption bottleneck to wireless multimedia communication.

III. Selection of Image Compression Parameters for Low Power Wireless Communication

As discussed in section II, varying JPEG image compression parameters can significantly affect the quality of image transmitted, the bandwidth required for transmission, the Quality of Service (latency) of transmission, and the energy required by image compression and communication. In this section, we propose a methodology to select the optimal JPEG image compression parameters to minimize the overall (computation as well as communication) energy consumption of the multimedia capable radio, while still meeting QoS (latency), bandwidth, and QoMD (image quality) constraints.

The complete methodology, shown in Fig. 6, consists of three steps. The first two steps precompute an *image quality parameters table* consisting of the quantization level and compression ratio (in bits per pixel) for each possible image quality (PSNR) and Virtual Block Size (VBS). The third step, performed on-line in the multimedia capable radio, uses the image quality parameters table to select the optimal image compression parameters for the current latency, bandwidth, and quality of image requirements, along with the current transmission energy/bit (set by the power amplifier to minimize inter-signal interference).

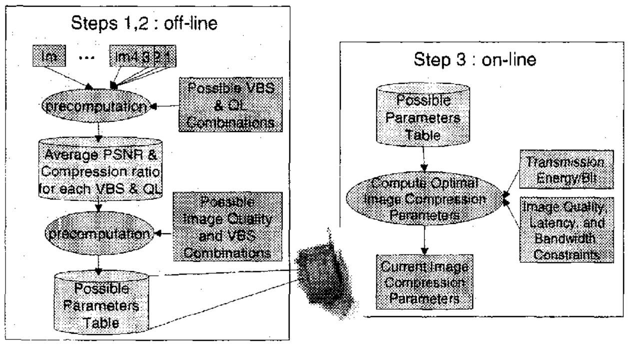

Fig. 6. Methodology for determining the optimal parameters for image compression

In the first precomputation step, the image quality (PSNR) and number of bits to transmit, as determined by the compression ratio, is precomputed for each VBS and quantization level combination. Since image quality and compression ratio values vary from image to image, an average over a large number of images is used. The result of step 1 is a table of PSNRs and compression ratios referenced by VBS and quantization level.

Precomputation step 2 uses the table computed in step 1 to determine a quantization level and compression ratio for each possible image quality and VBS combination. To determine the quantization level for a given image quality and VBS pair, a search is made in the table generated by step 1 for the largest quantization value which yields an acceptable image quality with the given VBS. The resulting quantization value, along with the corresponding compression ratio found in the table resulting from step 1, is stored in the image quality parameters table for use in the multimedia capable radio, as shown in Fig. 7.

Image Quality	VBS =8	VBS =7	VBS =6	VBS =5	VBS ...
...	...	...	...	...	
32dB	50, .989	49, .991	44, 1.05	28, 1.31	...
31dB	63, .825	63, .825	60, .858	49, .961	...
30dB	73, .688	72, .701	71, .711	66, .768	...
...	...	...	...	...	

Fig. 7. Example Image Quality Parameters Table

Algorithm for run-time selection of image compression parameters

Once the image quality parameters table is stored inside the multimedia capable radio, the radio must select, at run-time, which image compression parameters to use. During wireless communication, the multimedia capable radio monitors the image quality, latency, and bandwidth constraints, as well as the transmission power per bit for the current communication conditions and multimedia service. If there is a significant change in the conditions or constraints, step 3 of our methodology is performed in which the most appropriate image compression parameters are selected.

To determine the image compression parameters which will minimize the overall energy consumption of the mobile multimedia radio, the selection of the VBS and quantization level parameters, and their effects on both computation energy and number of bits transmitted (communication energy) must be considered simultaneously. For example, as shown in Fig. 8, to obtain a PSNR of 30dB, a tradeoff between computation energy and number of bits to transmit occurs when choosing different VBS values. The bottom line in the graph shows the decrease in computation energy as the VBS decreases. However, to maintain the same image quality, the quantization level must decrease, increasing the number of bits to transmit, and hence the communication energy, as shown by the top line in Fig. 8. Therefore, to choose the image compression parameters which will minimize overall energy consumption, step 3 of the methodology must consider not only the direct effect that choosing the VBS has on computation energy, but also the indirect effect on communication energy.

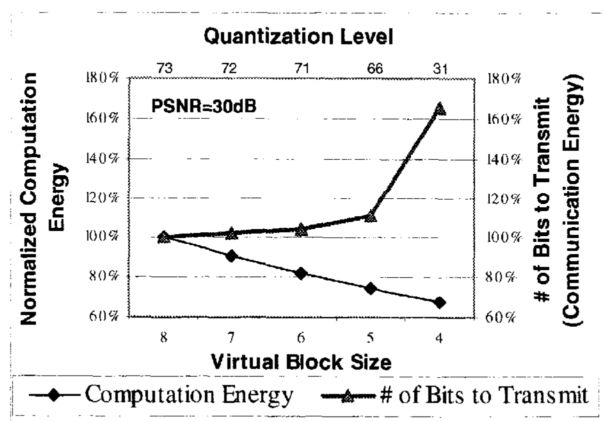

Fig. 8. The effect of decreasing VBS on computation energy and number of bits to transmit for a constant image quality

To guarantee the minimum overall energy consumption, the multimedia capable radio uses the algorithm shown in figure 9. For the required image quality (PSNR), and beginning with the largest VBS value (`curr_VBS=8`), the algorithm identifies the quantization level (`curr_QL`) and compression ratio (`curr_CR`) used to satisfy the image quality constraint by performing a lookup in the image quality parameters table. The multimedia capable radio then determines the overall energy dissipation (`curr_E`) by adding the computation energy (determined by VBS) and communication energy (determined as a product of uncompressed image size, compression ratio, and transmission power/bit). The algorithm compares the energy dissipation of the current VBS with the next smallest VBS (next_E). If choosing the next smallest VBS will increase the overall energy consumption, or violate the latency or bandwidth constraints, then the current VBS is chosen. If choosing the next smallest VBS decreases the overall energy consumption without violating latency or bandwidth constraints, then the algorithm decrements the VBS. The process is repeated till the optimal VBS (VBS) and quantization level (QL) parameters are identified.

```
SELECT_PARAMS (image_quality, latency, bandwidth)

curr_VBS=8
curr_QL, curr_CR = Lookup (image_quality, curr_VBS)
curr_E = computation_energy(curr_VBS) +
    (image_size * curr_CR * transmission_energy/bit)
next_QL, next_CR = Lookup (image_quality, curr_VBS-1)
next_E = computation_energy (curr_VBS - 1) +
  (image_size * next_CR * transmission_energy/bit)
while (next_E < curr_E) and
      (latency and bandwidth constraints met)
begin
  curr_VBS = curr_VBS-1
  curr_E = next_E
  next_QL, next_CR= Lookup(image_quality, curr_VBS-1)
  next_E = computation_energy (curr_VBS - 1) +
     (image_size * next_CR * transmission_energy/bit)
end
VBS = curr_VBS
QL = curr_QL
```

Fig. 9. Algorithm for step 3 of the proposed methodology

Energy Savings Due to Adaptive Image Compression

Using the methodology presented to select the optimal JPEG image compression parameters, the overall energy consumed in transmitting an image can be reduced. Fig. 10 demonstrates the energy savings available by adapting the image compression parameters to the current wireless multimedia communication conditions and constraints. It is assumed that the computation energy for compressing a full-color, 704x512 size image with a VBS=8 is equal to the energy consumed in transmitting a 30dB image compressed at VBS=8 (31kB). In the top line, the energy consumption of a non-adaptive radio which always transmits the image at 42dB is shown. The bottom line represents the energy consumption of an adaptive multimedia capable radio which computes and transmits only the needed image quality while meeting bandwidth and latency constraints, adjusting the image compression parameters according to the methodology presented. The adaptive radio consumes significantly less energy than the non-adaptive radio. For example, only 20% of the energy consumed by a non-adaptive radio is consumed by the adaptive radio for an image quality of 33dB.

IV. Conclusion

By adapting the source coder of a multimedia capable radio to current communication conditions and constraints, it is possible to overcome the bandwidth and energy bottlenecks to wireless multimedia communication. We have selected two parameters of the JPEG image compression algorithm to vary, and presented the results of modifying the parameters on quality of image, bandwidth required, computation energy, and communication energy. We have also presented a methodology which run-time selects the optimal JPEG parameters to minimize overall energy consumption, helping to enable wireless multimedia communication.

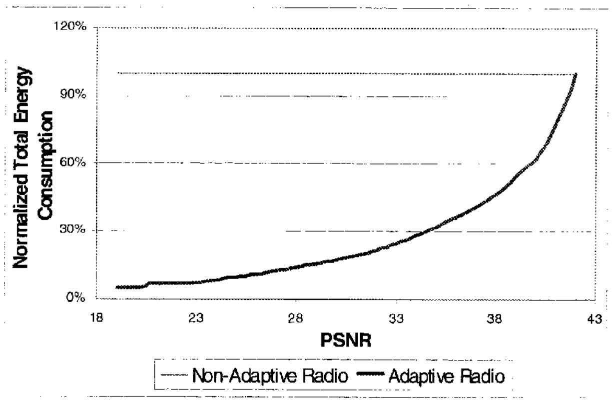

Fig. 10. A comparison of adaptive and non-adaptive multimedia radio energy consumption

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