Energy/Latency/Image Quality Tradeoffs in Enabling Mobile Multimedia Communication

Clark N. Taylor, Sujit Dey, and Debashis Panigrahi

Department of Electrical and Computer Engineering
University of California, San Diego
La Jolla, California, USA
{cntaylor, dey, dpani}@ece.ucsd.edu

Abstract: *Future wireless applications, such as cellular video telephony, wireless LANs and PANs, home networks, and sensor networks, point towards a growing demand for multimedia content in wireless communication. However, mobile multimedia communication has several bottlenecks including bandwidth requirements, low-power constraints, and channel noise. In this paper, we propose a method to overcome the energy and bandwidth bottlenecks by adapting to the varying conditions and requirements of mobile multimedia communication. We focus on source coding, which can have significant impact on both the computation and communication energy consumption of the multimedia radio, as well as the Quality of Multimedia Data transmitted and the Quality of Service (latency of transmission) achieved. In particular, we study the effect of varying some parameters of the JPEG image compression algorithm (a type of source coding) on energy, latency, and image quality. We present a methodology to enable selection of the appropriate image compression parameters to implement the energy/latency/image quality tradeoff in mobile multimedia radios.*

1 Introduction

With the growing popularity of new mobile multimedia applications such as cellular video telephony, wireless internet access, wireless LANs and PANs, home networks, and sensor networks, there will be a growing demand for fast, low-energy, mobile multimedia communication. Figures 1 and 2 illustrate the dramatic growth of mobile multimedia communication in one of these applications, wireless internet access. Figure 1 records and predicts a dramatic growth in the number of wireless internet users from 1996 to 2001. Figure 2 shows how the quantity of multimedia traffic is predicted to increase rapidly compared with voice traffic. The growth in the need and ability for wireless access to the internet, together with other applications requiring mobile multimedia communication, is fueling the need for wireless multimedia communication.

However, before high-quality mobile multimedia communication can be achieved, there are several bottlenecks which need to be addressed. First, the bandwidth requirements of multimedia communication can be very high. This bottleneck will be addressed in the future by new “3G” cellular systems including WCDMA[1, 2], CDMA2000[3], and HDR standards[4], as well as non-cellular standards such as Bluetooth[5] and IEEE 802-11a(b)[6].

In addition to bandwidth, energy consumption presents a significant bottleneck to mobile multimedia communication. As radios built for mobile multimedia communication will be powered primarily by battery, the energy consumed

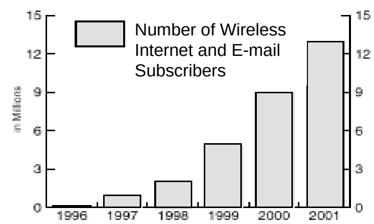

Fig. 1. Number of wireless users increasing exponentially (source phone.com)

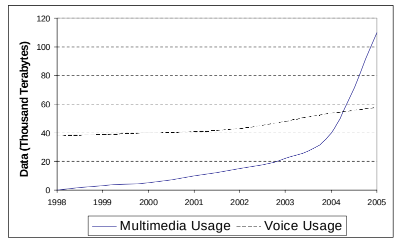

Fig. 2. Type of data transmitted over internet (source Analysys Ltd.)

must be minimal. In addition, a large amount of information is needed to represent multimedia data. Therefore, both the computation energy (energy consumed in processing information to be transmitted) and communication energy (energy consumed in wirelessly transmitting information) can be very high.

Another bottleneck to mobile multimedia communication is channel noise. As the number of mobile users increase, the interference between users will also increase, causing more channel noise. While many methods, such as retransmission and channel coding, exist for overcoming the effects of channel noise, more bandwidth and energy is required to implement these methods.

A characteristic of wireless communication which can be used to overcome the bandwidth and energy bottlenecks is that the conditions and requirements of wireless multimedia communication vary. Variations in channel conditions may be due to user mobility, changing terrain, etc. For example, in [7], 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 (image quality) requirements of transmitted data are different between video telephony and web browsing.

One way to design a multimedia radio is to assume the worst-case conditions and requirements. However, in this paper we show that by designing a mobile multimedia radio to adapt to the varying conditions and requirements of the communication system, we can overcome the bottlenecks of mobile multimedia communication.

For example, in Figure 3, we show three different cases of wireless communication of the same image. Because of the type of multimedia communication, the quality of the image is not very important, but the latency is constrained to 0.1 seconds. In case 1, the channel conditions are good, so the wireless radio handset receives a high quality image within 0.1 seconds. The bandwidth available in case 2, however, is lower, causing a high quality image transmission to take 1 second. However, this violates the latency requirements of the desired service. Case 3 shows that by adapting the image compression to the available bandwidth, the same latency as case 1 may be achieved. By sending a lower quality image than in cases 1 and 2, case 3 achieves a latency of 0.1 seconds, meeting the requirements of the multimedia communication.

There has been active research on adapting to current channel conditions to save energy and bandwidth. For example, in [8], the authors adapt the channel

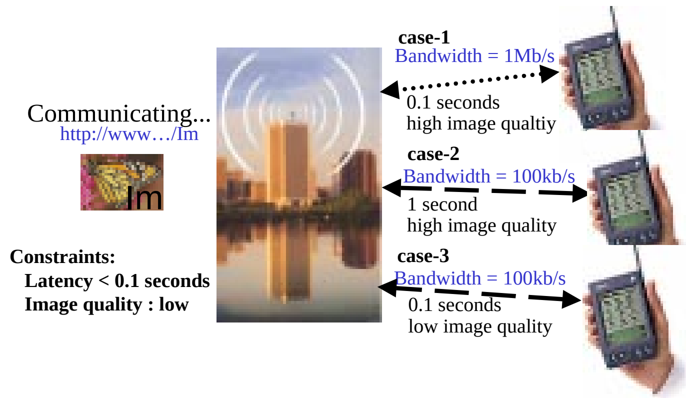

Fig. 3. Example adaptation of image quality to meet latency constraints

coding parameters used to match current channel conditions, thereby increasing the average bandwidth available. In [9], an algorithm is proposed to modify the broadcast power of a power amplifier to meet QoMD requirements, thereby lowering energy consumption. In [10], the authors change channel coding and power amplifier settings to adjust for current conditions, thereby lowering energy consumption.

In this paper, we present an approach to help overcome the bandwidth and energy bottlenecks in enabling mobile multimedia communication. By adapting a mobile multimedia radio to the current communication conditions and constraints, we can execute the right algorithms, with the right parameters, at the right time and cost, rather than consistently communicating as if in the worst case. This will maintain the necessary performance of the system while lowering the energy and bandwidth requirements.

An important component in mobile multimedia communication is the source coder. By changing the source coder algorithms and parameters, we can implement energy, latency, and QoMD tradeoffs according to the current system conditions and requirements to minimize energy and bandwidth. In this paper, we focus on one example of source coding, the JPEG image compression algorithm. We study the effects of varying parameters of the JPEG image compression algorithm in mobile multimedia communication. We also introduce a methodology to select the optimal image compression parameters to effect an energy/latency/image quality tradeoff.

This paper is organized as follows. Section 2 discusses how source coding can be used to adapt to communication conditions and constraints. Section 3 presents how changing JPEG image compression parameters effects the energy, latency, and image quality in mobile multimedia communication. Section 4 presents a methodology for selecting image compression parameters which minimize the energy consumption of a multimedia radio given the latency and image quality constraints of the communication. Section 5 concludes the paper.

2 Flexible Multimedia Data Compression and Communication

One of the issues that makes mobile 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 traditional 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. Traditionally, when configuring the source coder, only the tradeoff between the quality of multimedia data (QoMD) and the number of bits to be transmitted was considered. However, with wireless communication, source coding affects more than just QoMD and bandwidth. Figure 4 illustrates the effects of configuring the source coder through choosing different compression algorithms and parameters. The choice of source coding algorithms and parameters affects not only the bandwidth required and the QoMD, but also the Quality of Service (QoS) and energy consumption during wireless communication.

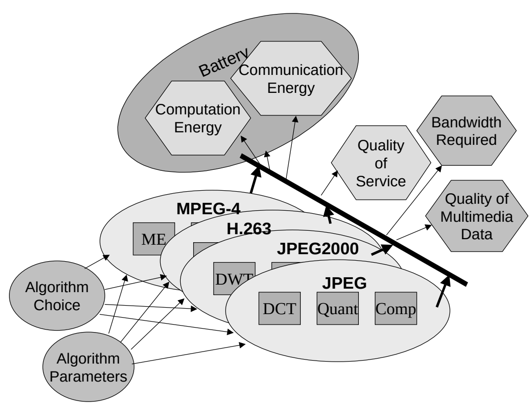

Fig. 4. Effects of source coding algorithms and parameters

For example, in Table 1, some of the tradeoffs between JPEG[11, 12] and JPEG2000[13, 14], two different image compression algorithms, are illustrated. For JPEG2000, the computation stage (source coding) consumes more energy and takes longer than when using the JPEG algorithm. However, because JPEG requires more bits to achieve the same image quality, the communication energy and latency for JPEG is greater than for JPEG2000.

To leverage the advantages of configuring a mobile radio to current communication conditions and requirements, we propose the mobile multimedia radio architecture shown in Figure 5. Our new architecture includes a traditional radio transciever (unshaded), consisting of a speech/data coder, channel coder, RF modulator, and power amplifier. Additionally, it will include an adaptive image/video source coder and Network Aware Operating System (NAOS), indicated by the shaded regions. The NAOS is responsible for understanding the

Table 1. Effect of different image compression algorithms on energy and latency requirements

Which Algorithm	Computation Energy	Computation Latency	Communication Energy	Communication Latency
JPEG2000	More	More	Less	Less
JPEG	Less	Less	More	More

current conditions and requirements of the radio and network, and configuring the adaptive image/video source coder accordingly. The adaptive image/video coder must be designed to handle different multimedia data compression algorithms, with their parameters, so that the NAOS can optimally configure it. With this architecture, we can leverage the variations in communication conditions and requirements to help overcome the bottlenecks to mobile multimedia communications.

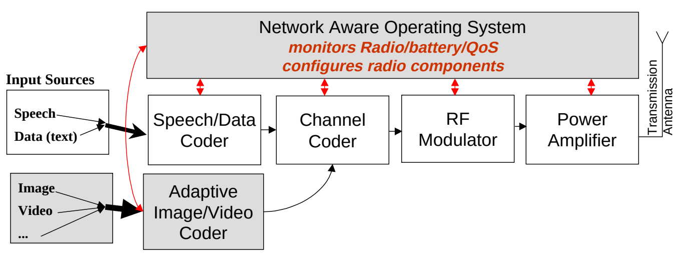

Fig. 5. Our Proposed Radio Architecture

In the next section, we investigate the effects of modifying the parameters of an existing source coding algorithm, JPEG image compression, on mobile multimedia communication.

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

As discussed in section 2, source coding affects not only the Quality of Multimedia Data (QoMD) transmitted and bandwidth required for communication, but also the energy and Quality of Service (latency) required in wireless multimedia communication. To better understand the effects of source coding on QoMD, bandwidth, energy, and latency, we present the results of varying the parameters to a commonly used source coding algorithm, JPEG image compression.

Figure 6 shows a basic flow diagram of the JPEG image compression algorithm. To implement JPEG, the input image is divided into blocks of pixels 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.

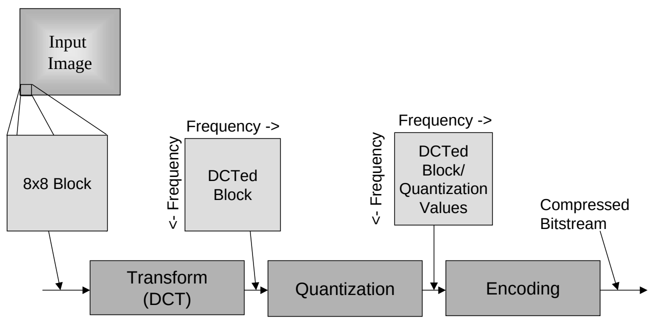

Fig. 6. Basic flow of JPEG image compression algorithm

To investigate the possible tradeoffs between energy, latency, and image quality, we selected 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 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 whose effects we study is Virtual Block Size (VBS). This parameter affects the DCT portion of JPEG as first introduced in [15]. 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. Figure 7 shows an example of setting the VBS to 8 and 5. When the block size is 8, all information frequency information is computed. When the block size is 5, all frequency data outside the 5x5 block is set to 0. By setting the components outside the VBSxVBS block to zero, less computation energy is required for smaller VBSs because the elements set to zero do not have to be computed or quantized. In addition, zeros require less information bits to transmit, lowering the computation energy as the VBS values decrease.

In the subsections that follow, we discuss the effect of varying the selected parameters (quantization level and VBS) on energy, latency, and image quality. We conducted our experiments using the Independent JPEG Group's C code [12] modified to implement VBS. All numbers presented are an average across four different images (monarch, peppers, sail, and tulips). 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. Communication energy and latency is measured by the number of bits needed for image communication. We have assumed the computation energy needed for compressing a full-color, 704x512 size image, with VBS=8, to be the same as the communication energy required in transmitting 280kb (35kB).

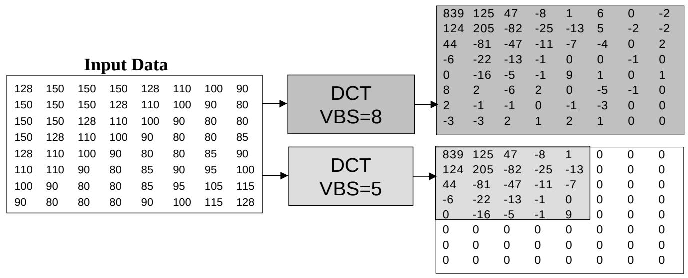

Fig. 7. An Example of virtual block sizes 8 and 5

3.1 Effects of Varying Quantization Level

Varying the quantization level of the JPEG algorithm has several effects on the mobile multimedia communication. First, increasing the quantization level reduces the image quality. Second, increasing the quantization level decreases the number of bits to be sent. This leads to a decrease in communication energy, latency and bandwidth required to send the image. Figure 8 illustrates how increasing the quantization level leads to a decrease in the image quality (PSNR) and communication energy (number of bits transmitted). The quantization values are linearly interpolated between quantization levels 0, 50, and 100, as defined by the IJG [12] (where 0 is no quantization and 100 is maximum quantization). The number of bits transmitted are normalized to compare against transmitting with no quantization.

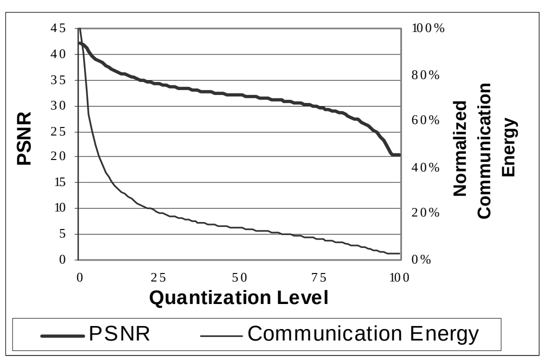

Fig. 8. Effect of varying the quantization level on image quality and communication energy (number of bits transmitted)

3.2 Effects of Varying Virtual Block Size

As mentioned before, the effect of Virtual Block Size (VBS) on computation energy and image quality has been studied before [15]. In this subsection, we present the effect of VBS on communication in addition to computation so that we can have a comprehensive knowledge of the tradeoffs present in using VBS.

As VBS decreases, the quality of image and the energy used in the DCT and quantization portion of the JPEG algorithm decreases, while the energy consumed in the encoding portion remains the same. In Figure 9 we show the decrease in image quality, computation energy, and communication energy as the VBS decreases. The amount of energy expended is normalized against when the VBS is 8.

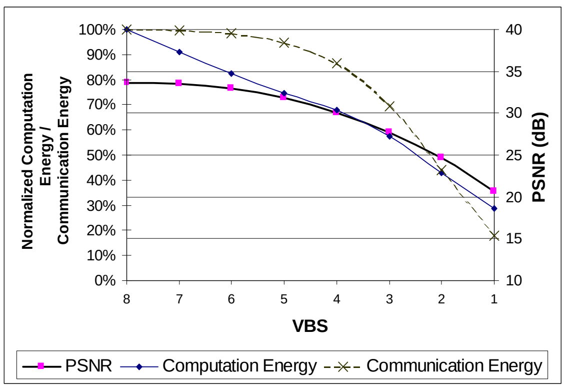

Fig. 9. Effect of varying the virtual block size on image quality, computation energy, and communication energy (number of bits transmitted)

Knowing the results of varying JPEG image compression parameters permits an intelligent tradeoff between energy, latency, and image quality in a multimedia radio. In the following section, we present a methodology which uses knowledge of image compression parameter effects to lower the energy consumption of a multimedia radio.

4 Selecting Image Compression Parameters for Optimal Energy/Latency/Image Quality Tradeoffs

As discussed in sections 2 and 3, varying image compression parameters can significantly affect the quality of image transmitted, the Quality of Service (latency) of transmission, and the energy required by a multimedia radio. In this section, we propose a methodology to select the optimal image compression parameters to effect the desired energy/latency/image quality tradeoff.

The objective of our proposed methodology is to minimize the overall (computation as well as communication) energy consumption, while meeting the specified QoS (latency) and QoMD (image quality) requirements. The complete methodology, shown in Figure 10, consists of a precomputation stage, which is performed off-line, and a table lookup step, performed by the multimedia radio. The off-line precomputation stage calculates an optimal parameters table consisting of the VBS and quantization level parameters to be used for each possible latency and image quality combination, such that the total energy is minimized. The NAOS in the multimedia radio uses the lookup table to determine the correct parameters for the current latency and image quality requirements. This approach ensures that the majority of the work done to determine the optimal parameters is performed off-line, thereby ensuring that the reconfiguration of the multimedia radio is fast and power efficient.

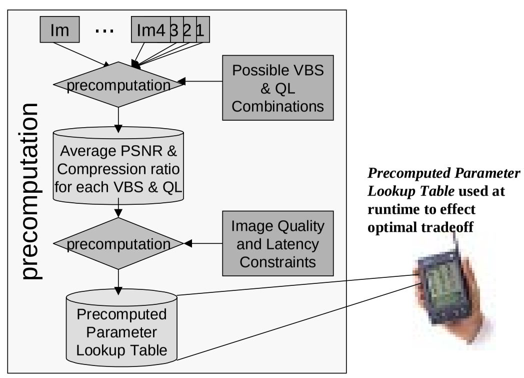

Fig. 10. Methodology for determining the optimal parameters for image compression

The precomputation of the optimal parameters table is performed in two steps. In the first step, the image quality (PSNR) and latency (number of bits to transmit as determined by the compression ratio) is precomputed. Since these 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, as shown in Figure 11.

	VBS	8	7	6	...
QL					
...		...	...	...	
19		35, 1.74	34.8, 1.72	34, 1.69	...
...		...	...	...	
25		34.1, 1.47	34, 1.46	33.4, 1.44	...
26		34, 1.46	33.9, 1.45	33.3, 1.43	...
...		...	...	...	

Fig. 11. Example PSNR and compression ratio table referenced by VBS and quantization level

The goal of the second step of precomputation is to generate a lookup table which, given the image quality and latency constraints, minimizes the total energy consumed in compressing and wirelessly transmitting an image. We present below two algorithms which can be used in implementing the second step. Both algorithms rely on the table generated in the first step to determine the VBS and quantization level to use.

The *VBS-first* algorithm starts by finding the smallest VBS which can yield the required image quality (PSNR), then choosing the largest quantization level which still meets the image quality requirement. If latency constraints are not met (as determined by the compression ratio obtained), then the next larger VBS is chosen and the process repeats. The advantage of using the *VBS-first* algorithm to select the compression parameters is that the resulting image compression (performed by the multimedia radio) is very energy efficient.

However, choosing the smallest VBS possible may not always be sufficient for lowering the overall energy consumption. For a constant image quality (PSNR=32dB), Figure 12 shows the effects of varying the VBS on the computation and communication energy, normalized for when the VBS is 8. As the VBS decreases, the computation energy decreases, as expected. To maintain the same PSNR, however, the quantization level must be decreased, as shown at the top of the graph, leading to an increase in compression ratio (and number of bits transmitted), and hence the communication energy required. This shows that lowering the VBS can actually cause an increase in communication energy.

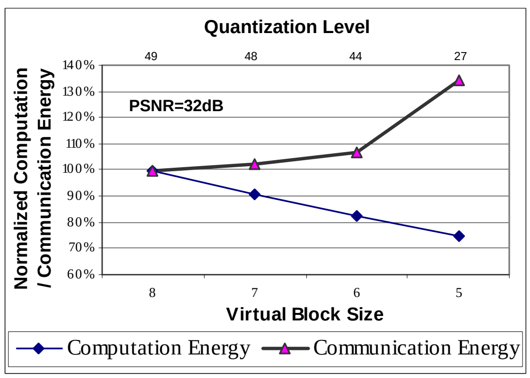

Fig. 12. Difference in Computation and Communication Energy with a constant PSNR and decreasing VBS

An alternative algorithm (*simultaneous*), aims to minimize the total computation and communication energy consumed by a multimedia radio to transmit an image by simultaneously determining the VBS and quantization level parameters. To determine both parameters at the same time, the algorithm first searchs through all possible VBSs and determines the quantization levels needed to meet the image quality constraint for each VBS. For each VBS and corresponding quantization level, the overall energy can be computed. The computation energy is determined by the VBS chosen, while the communication energy is determined by using the compression ratio found in the PSNR and compression ratio table referenced by VBS and quantization level. In this way the algorithm can compare the results of all possible VBSs and choose the one which minimizes overall energy consumption while still meeting the constraints of the communication.

For example, given the PSNR and compression ratio table found in Figure 11, a VBS of 7 and quantization level of 25 would be chosen by *simultaneous*, while *VBS-first* would chose a VBS of 6 and quantization level of 19. This is because the necessary increase in quantization level from VBS=7 to VBS=6, and corresponding compression ratio (communication energy) increase, cancel out the decrease in computation energy.

Figure 13 compares the total energy consumption of the multimedia radio when the image compression parameters are selected by the *VBS-first* and *simultaneous* approaches. The top line, which often consumes more energy, is the overall energy consumption when using the parameters chosen by *VBS-first*. The bottom line represents the overall energy consumption when using the *simultaneous* algorithm. As shown, the total energy consumed by the multimedia radio can be significantly lower when the *simultaneous* algorithm is used as opposed to the *VBS-first* algorithm. For example, to compress and transmit an image with PSNR=37dB, using the *simultaneous* algorithm leads to an energy consumption that is 1.97 times smaller than the energy consumption when *VBS-first* is used. The lower energy consumption achieved by the *simultaneous* algorithm is because it considers both computation and communication energy when effecting tradeoffs.

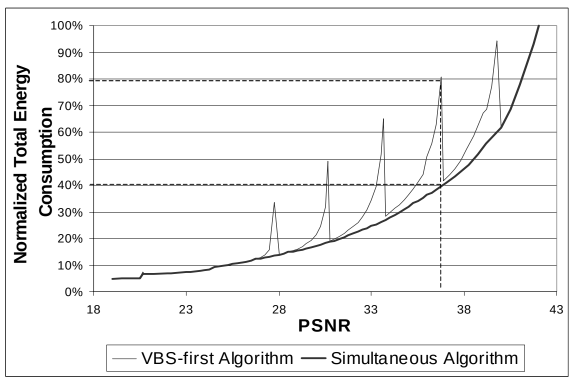

Fig. 13. A comparison of total energy consumption in a multimedia radio using image compression parameters from *VBS-first* and *simultaneous*

Once the optimal parameters table has been computed in step 2, the table can be stored in the multimedia radio for on-line use to determine the optimal compression parameters for the desired energy/latency/image quality tradeoff. The NAOS in the radio determines the image quality (QoMD) and latency (Qos) requirements and performs a table lookup to determine the optimal parameters. It then configures the adaptive image/video coder appropriately. This ensure the multimedia radio meets the QoMD and QoS requirements of the multimedia communication, while minimizing the energy consumed by the radio.

5 Conclusion

In this paper, we have discussed some of the major bottlenecks facing mobile multimedia communication. These bottlenecks include bandwidth, energy consumption, and channel noise. While upcoming wireless standards address the bandwidth limitation; energy consumption and channel noise are still significant bottlenecks to mobile multimedia communication. We proposed that by adapting to current communication conditions and requirements, we can overcome the bottlenecks to mobile multimedia communication.

An important component of multimedia communication is the source coder. The source coder affects not only the quality of multimedia data and bandwidth required, but also the quality of service provided and energy consumed by a multimedia radio. We proposed a new radio architecture which, in addition to traditional radio components, includes a Network Aware Operating System and adaptive image/video coder to adapt the source coding algorithms and parameters to the conditions and constraints of the current communication.

To better understand the effects of source coding on energy consumption, latency in transmission, and quality of multimedia data transmitted, we presented the results of varying parameters of the JPEG image compression algorithm. Using this information, we presented a methodology for choosing image compression parameters which allows us to efficiently tradeoff energy, latency, and image quality.

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