IMAGE AND VIDEO COMPRESSION FOR WIRELESS NETWORKS

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Abstract. The demands for transmission of image, video and multimedia over wireless networks are increasing very rapidly. The inherently characteristics of wireless medium as bandwidth narrowing, interferences and fading are big challenges. The traditional compression techniques can not adapt to this changes. In this paper, we will discuss of issues of using wavelet compression for image and video over wireless networks. This paper also introduces some change of wavelet parameters in order to improve quality of transmission image and video over wireless network conditions.

1. Introduction

The traditional mobile networks are used for low – rate audio communications. New generation of mobile communications is emerging to transfer data trafic at much higher bit rate. The demands for multimedia, image and video over wireless networks are rapidly increasing. Future Internet will allow users access from mobile appliances (PDAs, smart phone, Web pads, hand PCs...) and high bandwidth applications (m-commerces, multimedia E-mail, video telephone, wireless LANs, PANs).

Transmission of Image and Video over Wireless Networks are challenging because of the highly variable nature of the wireless link. Radio is an inherently unreliable transmission medium when compared to a wired link due to inteference and fading create higher bit errors. Typical wireless channels are noisy and of narrow bandwidth. For example, a customer using a code-division multiple-access (CDMA) has only a 9.6 kbps bandwidth. Even if the bandwidth increases up to 2 Mbps for the 3G wireless, it is still not comparable to the bandwidth of broadband optical communication systems (ATM could allocate dozens of Mbps to end users). Time-varying characteristics of wireless channel and limited battery resource in handheld devices is another issue for scalable video streaming over wireless link with Quality of Service (QoS). Meanwhile, the capacity of a wireless channel is fluctuated due to the changing distance between the transmitter and the receiver. So it is important to estimate the available wireless network condition dynamically and it is necessary to apply appropriated video compression strategy to handle the variability of wireless networks.

2. Image compression techniques

There are four common methods for compression, Discreate Cosine Transform (DCT), Vector quantization (VQ), Fractal Compression and Discrete Wavelet Transform (DWT).

DCT is a lossy compression algorithm that samples an image at regular intervals, analyzes the frequency components present in the sample, discards those frequencies which do not affect the image as the human eye perceives it.

Vector quantization (VQ) is a lossy compression that looks at an array of data, not an individual value. It compresses redundant data while at the same time retaining the desired object or data stream's original intent.

Fractal compression is a form of VQ and is also a lossy compression. The self-similar sections of image is located and then using fractal algorithm to handle them.

DWT analyzes signals into wavelets-functions that have both time and frequency domains. The process is perform on the entire image, which differs from DCT that works on smaller block (8 x 8 picxels).

2.1 Discrete Cosine Transform (DCT)

Currently, DCT is quite popular in many compression products such as **JPEG**. Image compression using DCT is illustrated in figure 1.

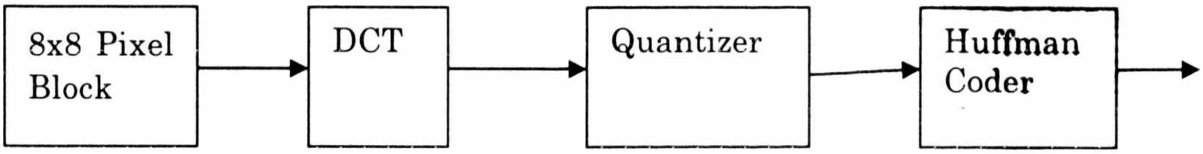

Figure 1. JPEG compression.

The general forward and inverse DCT transform for a 2D (*N* by *M* image) is defined by the following equation

DCT:

$$F(u,v)=\frac{2}{N}C(u)C(v)\sum_{y=0}^{N-1}\sum_{x=0}^{M-1}f(y,x)\cos\frac{(2x+1)v\pi}{2N}\cos\frac{(2y+1)n\pi}{2N} \tag{1}$$

IDCT:

$$f(i,j)=\frac{2}{N}\sum_{u=0}^{N-1}\sum_{v=0}^{M-1}C(u)C(v)F(u,v)\cos\frac{(2x+1)u\pi}{2N}\cos\frac{(2y+1)v\pi}{2N} \tag{2}$$

The main disadvantages of DCT is that when the coded bit rate is lower than a certain value (0.25 bits/pixel), there are blocking effects in the decoded image, due to the 8 x 8 block two dimensional DCT. In another issue, for the wireless networks, the channels are noisy, the blocks are lost because Huffman coding is a variable length code. The noisier the channel is, the more blocks are lost.

2.2 Discrete Wavelet Transform (DWT).

2.2.1 The wavelet decomposition has been proved to be a good tool for image compression recently. It performs better than DCT in term of compression ratio and quality of picture which is reproduced. The new JPEG 2000 standards adopt wavelet subband coding, where the encoder tiles the image into blocks of N x N pixels (N being a power of 2), calculates a 2-D Discrete Wavelet Transform (DWT), quantizes the transform coefficients and encodes them using arithmetic coding. The discrete-time wavelets have general form:

$$\Psi_{(a,b)}(t) = \frac{1}{a^{-1/2}} \Psi\left(\frac{t-b}{a}\right) \tag{3}$$

The variable a is used to scale the wavelet $\psi(t)$ by powers of two and variable b is used to translate the wavelet in integer amounts. To analyse data at different resolution, a function $W(t)$ is used in conjunction with the mother wavelet. Here

$$W(t) = \sum(-1)^k C_k \Psi(2t+k) \tag{4}$$

C_k are the wavelet coefficients which satisfy (5).

$$\sum_{k=0}^{N-1} C_k = 2 \text{ and } \sum_{k=0}^{N-1} C_k C_b = 2\delta_{b,0} \tag{5}$$

In this case δ is the delta function and b is the location index.

In forward DWT, image is seperated into low-pass samples, representing a low-resolution version of the original image and high-pass samples, representing a details which are needed for the perfect reconstruction of the original image.

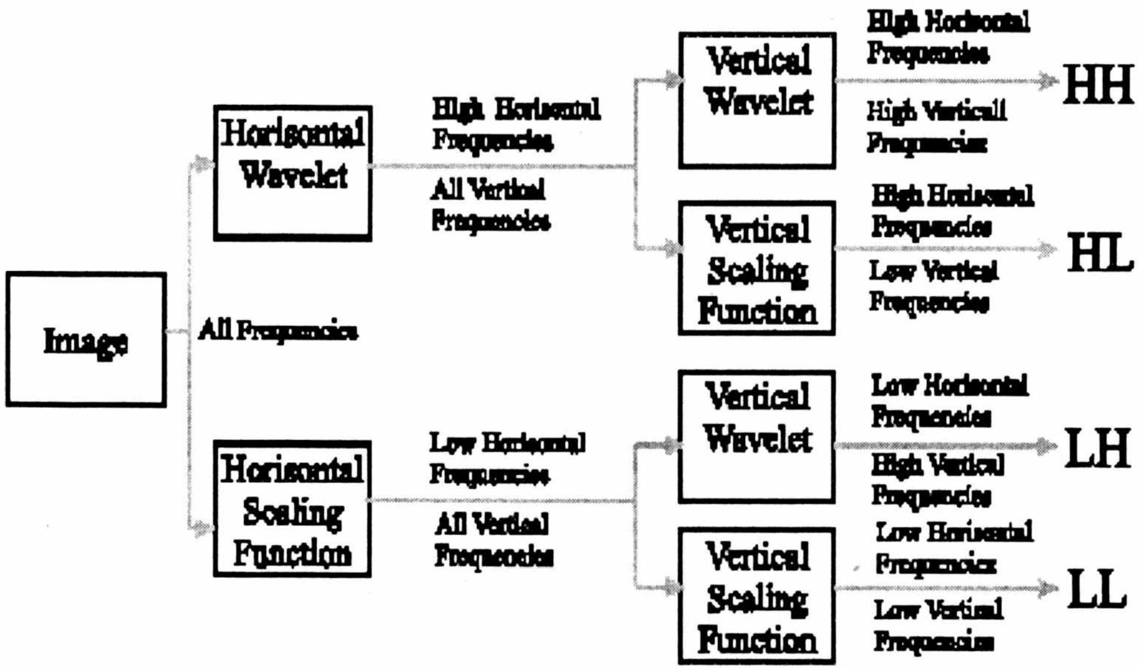

Figure 2. The level 1 of wavelet decomposition process

The entire process is carried out by excuting a 1-D subband decomposition twice, first in horizontal then in the veritcal (orthogonal). For example, the low pass subband (L1) resulting from the horizontal is further decomposed in the veritcal, leading to LL1 and LH1 subband. Similarly, the high pass subband H1 is further decomposed into HL1 and HH1. An example of the proccess of one level wavelet decomposition is depicted in figure 3 and the demonstration of picture is shown in figure 4..

Figure 3. The proccess of one level wavelet decomposition.

The second level of decomposition can be repeated for existing LL1 subband. This iterative process results in multiple"transform levels". If an image is decomposition into K levels then the total number of subbands is 3 K + 1. The process of decomposition of an image in three level as shown in figure 3. Number of required subbands after three level decomposion of 2D image is depicted in figure 5.

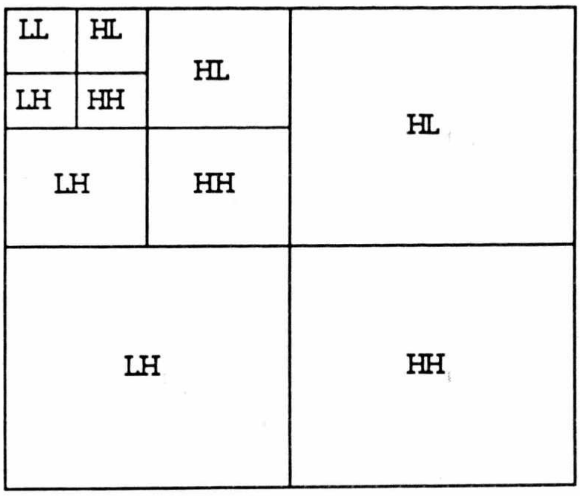

Figure 4. Three level of 2-D Discrete Wavelet Decomposition

2.2.3 Quantization is the process by which the coefficients are reduced in presision. The quantization can be lossy or lossless.

Each subband of the wavelet decomposition is divided into rectangular blocks (Code blocks), which are coded independently using arithmetic coding. These code-blocks are coded at a bit-plane at a time, starting with the most significant bit-plane with a non-zero element to the least significant bit-plane.

2.2.4 Wavelet has some main advantages over DCT, includes:

- Improved scalability: This is because the wavelet transform process can be repeated for as many time as needed. The decoder can stop any time if needed, as full resolution of the image may not required.
- Higher efficiency at low bit rates.
- It provide higher compression ratio and better quality of reproduced image.
- The disadvance of it is using wavelet require more calculations when comparing with DCT. This leads to more complexing in the hardware and software implementations.

2.3. The JPEG (Joint Photographic Experts Group)

JPEG is well-known image compression method based on DCT algorithm. JPEG compression can be done at different user defined compression levels, which determine how much an image is to be compressed. The compression level is directly related to the image quality. Besides the compression level, the image scene itself also has an impact on the resulting compression ratio. The same compression level applied on simple scene may produce a smaller file (higher compression ratio) than on a very complex and patterned scene (lower compression ratio).

2.4. JPEG 2000 standards.

The JPEG standards using DCT and JPEG 2000 using DWT. The difference in quality of image when compressed using JPEG and JPEG 2000 can be seen in the figure5.

JPEG 2000 standard provides a set of features that are of vital importance to many emerging applications. Some of the features that this standard possesses are:

Superior low bit-rate performance: This offers better performance than current standards at the low bit-rate.

- Lossless and lossy compression.
- *Progressive transmission by pixel accuracy and resolution*: Progressive transmission allows pictures to be reconstructed with increasing pixel accuracy or spatial resolution. This needs for many applications and for different target devices.
- *Region of Interest Coding:* This feature allows user defined Regions-Of-Interest (parts of a image that are more important than other parts of it) in the image to be compressed with better quality than the rest of the image.

- *Robustness to bit-errors:* It is desirable to consider robustness to bit-errors while designing the codestream. This feature is very important for wireless communication applications.

Original Image

40:1 compressed JPEG

40:1 Compressed JPEG 2000

Figure 5. Compare the quality of image using JPEG and JPEG 2000.

3. Video compression Technology

3.1. Video compression is performed when an input video stream is analyzed and redundant information is discarded. Each event is then assigned a code-commonly occurring events are assigned few bits and rare events will have more bits. This is called variable length encoding respectively (VLC). One of the best-known video streaming techniques is the standard called MPEG (*Motion Picture Experts Group*). The basic principle of MPEG is to compare two compressed images to be transmitted over the network and using the first compressed image as a reference frame (called an I-frame), only sending the parts of the following images (B-frame and P-frame) that differ from the reference image.

3.2. There are five MPEG standards being used. Each standard was designed for a specific application and bit rate MPEG-1 was designed for up to 1.5 Mbps, standadized for compression of moving pictures and audio. MPEG-2 was designed for between 1.5 and 15 Mbps. It is based on MPEG-1, but for the compression and transmission of digital broadcast television. The most significant enhancement from MPEG-1 is its ability to efficiently compress interlaced video.

The Motion Picture Experts Group (MPEG4) standards for multimedia and Web compression. MPEG-4 is based on object-based compression. Individual objects within a scene are tracked seperatly and compresses together to create an MPEG-4 file that is very scalable, from low bit rates to very high.

MPEG-4 is a new generation of Internet-based video applications and Video Coding Experts Group H.264 standards for video compression is now widely used in videoconferencing systems. MPEG 4 and H 263 promises to significant outperform, providing better compression of video together with a range of features supporting high-quality, low bit-rate streaming video.

3.3. The H.261 and H.263 standards. H.261 is an ITU standard designed for two way communication over ISDN lines (Videoconferencing) and supports data rates of multiples of 64Kbps. The algorithm is based on DCT and can be used in intra-frame and inter-frame mode. H.261 supports CIF and QCIF resolutions. H.263 is based on H.261 with enhancements that improve video quality over modems. It supports CIF, QCIF, SQCIF, 4CIF and 16 CIF resolutions.

The H 264 standard does not explicitly define a CODEC, rather the standard defines the syntax of an encoded video bitstream together with the method of decoding this bitstream. The basic functional elements (prediction, transform, quantization, entropy encoding) are little different from MPEG1, MPEG2, MPEG-4, H.261, H.263.

3.4. The MPEG1, MPEG2, MPEG4, H.261, H.263 use 8x 8 DCT transform. The "Baseline" profile H.264 uses three transform depending on the type of residual data that is to be coded: a transform for 4 x 4 array of luma DC coefficients in intra macroblocks, a transform for 2 x 2 array of chroma DC coefficients in any mocroblock and a transform for all other 4 x 4 blocks in the residual data. H.264 uses scalar quantizer.

4. Video over Wireless Network

4.1. Supporting video over Wireless Networks is a hard problem because of three factors:

- Scarcity of bandwidth.
- Time-varying error characteristics of the transmission channel.
- Power limitations of the wireless devices.

The emerging of 3G wireless networks such as GPRS (General Packet Radio Service), CDMA (Code Division Multiple Access), CDMA2000, W-CDMA boosts enormous development of wireless video and services.. They are designed with the capability of providing high speed data services, ranging.from more than 100Kbps to several Mbps. However, transmission of video and mulitmedia streams over wireless networks still faces several challenges. Firstly, transmission of video over wireless channel is highly prone to errors due to multi-path effects, shadowing and interference. Secondly, the bandwidth of wireless channel can vary significnatly over time. The reason is the amount of bandwidth that is assigned to a user can be a function of the signal strength (low signal strength, more processing gain at the receiver and different bandwidth may be dynamically assigned to the user) and interference level (high interference condition, heavier channel coding). Thirdly, multi-user sharing the wireless channel with heterogenous data types can also lead to significant bandwidth variation which can further lead to overflow of network buffer and hence packet loss. Finally, data transmission can be interrupted completely depending on wireless implementation (handoff process, cell reselection)

4.2. Quality of Service (QoS) control in wireless networks can help alleviate the bandwidth variation and packet delay/loss problem but it is often costly. For example, to maintain a reasonable data rate for a user near the cell boundary, a large proportion of power of base station (BS) needs to be assigned which limiting the capacity of the BS to serve other users. Video standards MPEG-4 has a set of tools providing improved compression efficiency and error resillience. In addition, MPEG-4 provides scalability for both spatial and temporal resolution enhancements. Error control and power control are two very effective approaches for supporting quality of service. Error control is performed from individual user point of view by introducing redundancy to combat the transmission errors. One of the popular error coding techniques is Reed-Solomon coding, which can deal with burst error. If the original message length is M, we will add parity data, so the codeword is of length N > M which can recover errors of length up to (N-M)/2.By adding extra parity data of length R bytes, at least part of errors can be recovered by the receiver. The larger the value of R, more the errors will be corrected. Choosing of R should be considered carefully because parity data introduces more trafic to the limited network bandwidth and may cause packet loss due to congestion.

4.3. The Peak Signal-to-Noise Ratio (PSNR) measures the size of error relative to peak value of the signal X_{peak}. In other word, it is used to measure the fidelity of a compressed image with its original. High PSNR means that the compressed image is very similar to the original. The formular to calculate PSNR is

$$10\log_{10} {(X_{peak}^2)}\Big/{\sigma^2 * d} \qquad (6)$$

where X_{peak}^2 is the peak value of the signal and $\sigma^2 * d$ is the Mean Square Error MSE

Mean square error (MSE) measures the difference between the original and reconstructed image is calculated by

$$\sigma^2 = (1/N)\sum(X_n - Y_n)^2 \tag{7}$$

Here, X_n, Y_n, N are the input data sequence, the reconstructed data and the length of data sequence

The Wavelet transform with the advantage of multiresolution is good solution for improving PSNR. We will compare PSNRs for different resolutions with same compression ratio in table 1.

Table 1. Comparison of PSNR's Lena colored image of size 512 x 512 for different resolutions

Compression Ratio	Original (bits)	No. of resolutions (K)	After compression (bits)	PSNR (dB)		
				RED	GREEN	BLUE
0.01	6291456	1	62669	14.835608	17.382185	19.314852
		2	62505	21.426299	22.403615	20.806499
		3	62505	28.116940	28.457747	27.138719
		4	62669	30.337381	29.919802	28.922634
		5	62751	30.498237	30.167494	29.289699
		6	62669	30.424699	30.163027	29.162789

4.4. Power control is performed by controlling the transmission power and transmission rate for a group of users. So error control and power control techniques are necessary to ensure high-quality video delivery from application level and transmission level.

It.is necessary to understand overall wireless system performance (such as capacity) when multiple types of traffic, each with distinct characteristic are present in the same sector.

5. New trends in image and video compression

5.1. Currently, video communications are carried out using source coders and channel coders designed independent of each other based on the theoretical foundation of Shannon's "*separation principle*" , which states that this separation is optimal [4].

However, when considering wireless video communications, there are some reasons not to adhere to the separation principle. For example, Shannon's work make no assumption about the error characteristics of the channel on which data would traverse. It also doesn't take into account the optimization possible in channel utilization through statical multiplexing. This is true for all popular video standards, including MPEG-1, MPEG-2, H.261 and H.263. Coders are designed with little regard to the error characteristics of the channel.

5.2. Although existing compression techniques help fit video streams into the bandwidth available in wireless channels, there are a number of issues which affect the memory, computational capabilities and internal data transfer channels of wireless devices. In addition, the wireless communication environment is highly prone to introduce errors into digital bit streams. The video compression algorithms remove much of the redundancy in video data, and as a result, the effects of channel interference ripples through not just the current image being display, but also successive images.The predictive techniques used in MPEG cause errors in a reconstructed video frame to propagate through time into future frames. This can also cause to lose synchronization in decoding process.

5.3. The selection of an image compression algorithm for video and multimedia communication depends not only on the traditional criterial of achievable compression ratio and the quality of reconstructed images, it also depends on associated energy consumption and robustness to higher bit error rates. Wavelet algorithm enables significant reduction in computation as well as communication needed, with minimal degradation in image quality. Study has shown that the wavelet step consumes more than 60% of the CPU time during image compression process. By using optimizing algorithm of the transform step, performance and energy requirements of the entire image compression process can be significantly improved.

5.4. We know that forward wavelet transform uses a 1-D subband decomposition process where a 1-D set of samples is converted into the low-pass subband (Li) and high-pass subband (Hi). Dong-Gi Lee and Sujit Dey have presented a wavelet- based transform algorithm that aims at minimizing computation energy (by reducing the number of arithmetic operations and memory accesses) and communication energy (byreducing number of transmitted bits) in "Adaptive and Energy Efficient Wavelet Image Compression For Mobile Multimedia Data Services" [7]. Their idea is exploits the numerical distribution of the high-pass coefficients to eliminate a large number of samples in the compression process. The work shows that on the [512x512] Lena image sample, the distribution of high-pass coefficients after applying a 2 level wavelet as following (see figure 6).

We observe that about 80% of the high-pass coefficients for level 1 are less than 5. In the quantization step, all small valued coefficients are set to be zeros, so a lots of high-pass coefficients do not have to be computed. This has two advantages: firstly, the algorithm helps to reduce the computation energy consumed during image compression process and secondly, because the encoder and decoder are aware of the estimation technique, only small amounts of information need to be transmitted across the wireless channel, thereby reducing the communication energy required.

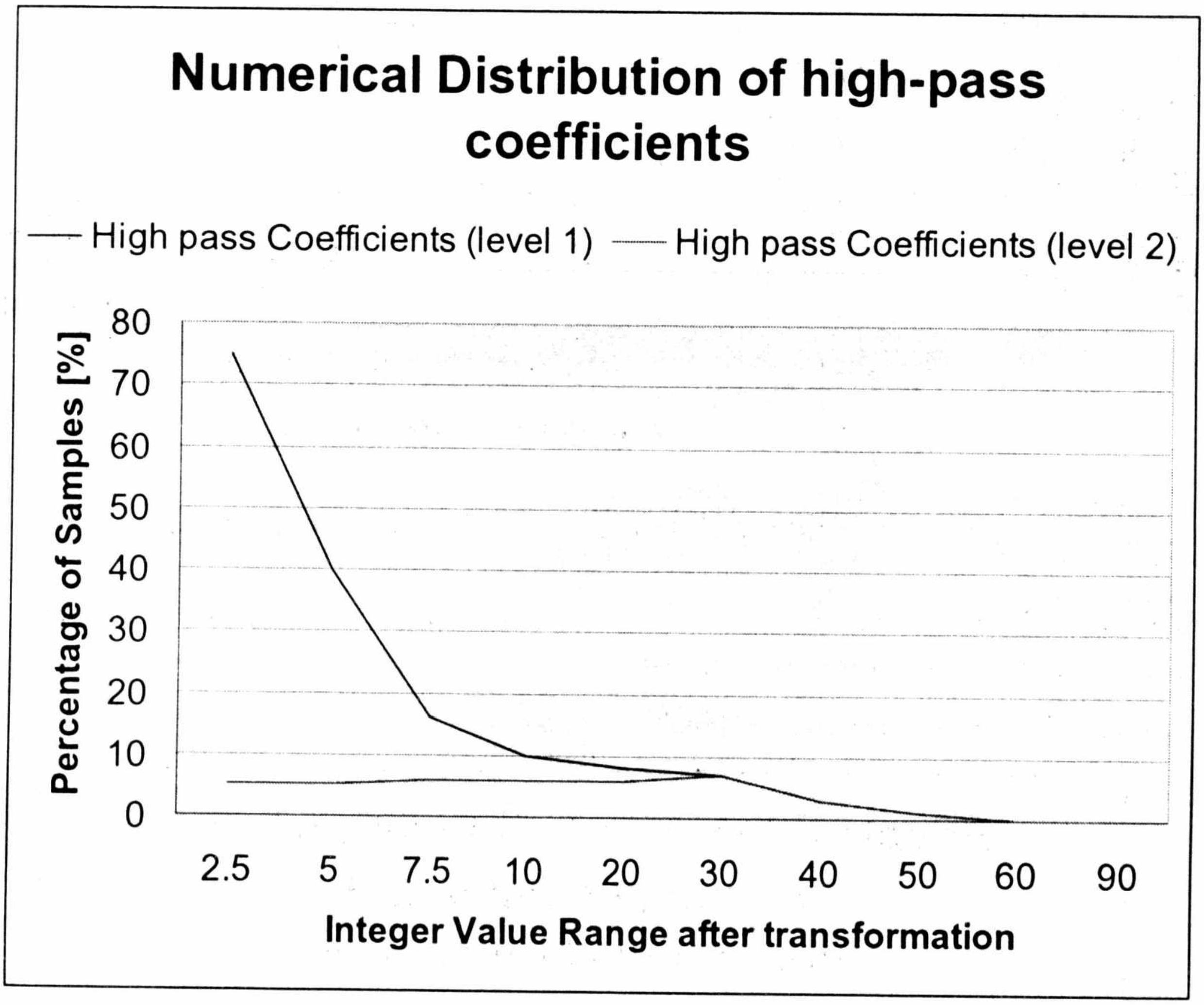

Figure 6. Numerical distribution of high-pass coeeficients after wavelet transform at level 2.

5.5. Besides the elimination techniques we have introduced, we can vary some other wavelet parameters, which can be used to minimize computation and communication energy consumed.

5.5.1. Varying Wavelet Transform Level.

As mention before, increasing the wavelet transform level can reduce the number of transmitted bits, leading to less communication energy. However, increasing the transform level also results in an increase in computation energy consumption. Figure 7 shows the effects of four different transform level on computation and communication energy.

In mobile communication, when handheld is transmitting data, communication energy will dominate computation energy, so that higher transform level may bring significant overall energy savings.

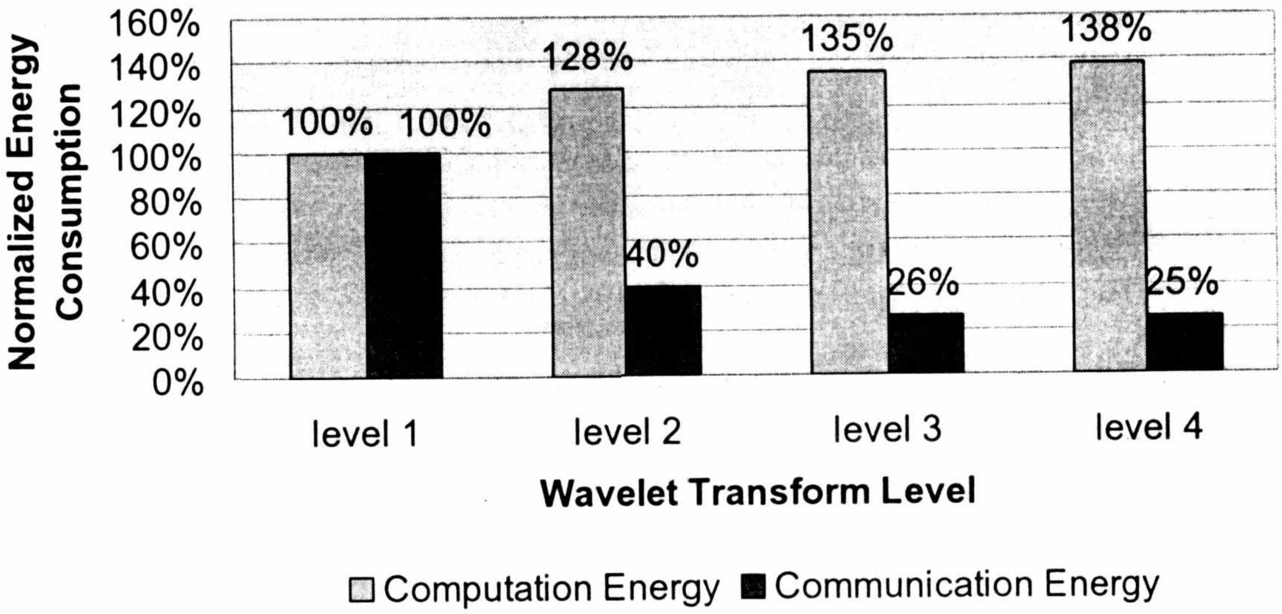

Figure 7. Effects of varying wavelet transform level on energy consumption (computation and communication energy).

5.5.2. Varying quantization level

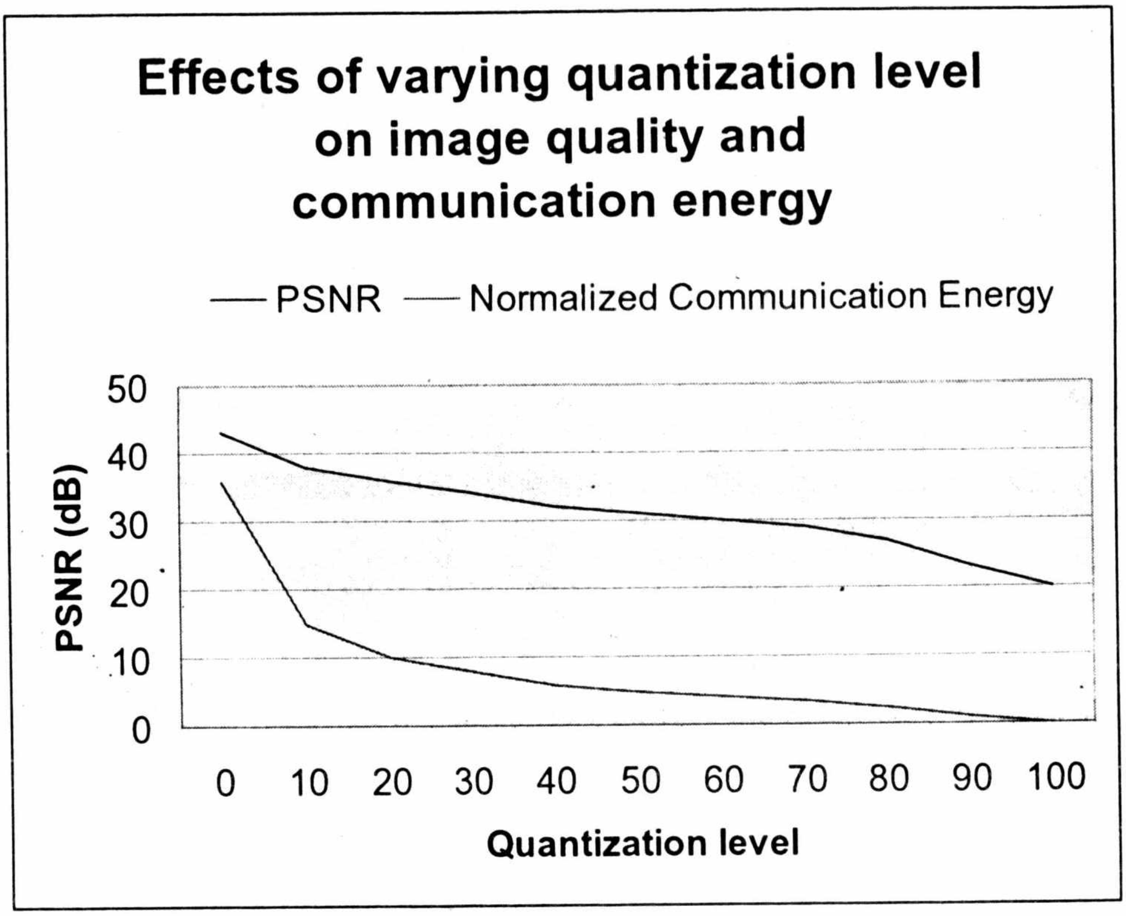

Figure 8. Effects of varying quantization level on image quality and communication energy.

The purpose of quantization is to reduce the entropy of the transformed coefficients so that the target bit rate can be met. Each of the transform coefficients $a_b\ (u,v)$ of the subband b is quantized to the value $q_b\ (u,v)$ according to the formula

$$q_b(u,v) = sign\left(a_b(u,v)\right)\left\lfloor \frac{\left|a_b(u,v)\right|}{\Delta_b} \right\rfloor \tag{8}$$

The quantization step size Δ_b is represented relative to the dynamic range of subband b. Each subband has separate quantization step-size and only one quantization step-size is allowed per subband [8].

Varying the quantization level of the wavelet compression has several effects on mobile communication. By increasing the quantization level, the number of transmitted bits will decrease, leading to a lower bit rate, less communication energy and bandwidth required. Of course, there is negative effect such as the image quality will degradation.

6. Conclusion

Future deployment of mobile multimedia data servies and wireless video will require very large amounts of data to be transmitted. However, transmission of image and video over mobile and wireless network have some bottlenecks, including limited bandwidth, channel noise, battery constrains of the appliances. This paper present some Image and Video comprecion popular techniques, some challenges of wireless networks for high bit rate data. We propose some ways to improve the quality of transmission of video and multimedia over wireless networks. Based on wavelet image compression, we give some ideas to change parameters of wavelet compression technique at the source, which in turn will have to adapt to the verying wireless network condition.

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