Unequal Importance Image Communication over Heterogeneous Networks

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Abstract—An unequal importance communication approach, for cheap, reliable and real-time image communication over heterogeneous networks and its applications in mobile multimedia communication systems is presented. Here, an image is partitioned into different layers of importance: base layer and enhancement layers. The low-rate base layer description, which can be strongly protected, is transmitted through a low-bandwidth, but robust and more expensive channel, supporting delay-sensitive applications (e.g. GSM network), while the high-rate enhancement layer description(s) are transmitted through a high-bandwidth, but high/variable-delay and cheap channel which does not support delay-sensitive applications (e.g. WLAN). In the receiver, when the base layer description is quickly received, an acceptable quality image is reconstructed, and when the enhancement layer description(s) are received a high quality image can be reconstructed. Our practical results indicated that this effective, flexible, and highly compatible method not only facilitates high quality image distribution among heterogeneous networks and increases the coverage, quality of service, and bandwidth and power efficiency but also decreases the delay and cost of image distribution in mobile communication systems.

Keywords—heterogeneous networks, image transmission.

I. INTRODUCTION

The present and future telecommunication environment is consisted of a large number of wired/wireless networks and communication systems with different characteristics, features, constraints and technologies which are called Heterogeneous Networks. Also, nowadays the rapid growth of wireless communication has resulted in a demand for robust transmission of multimedia contents, with better quality and coverage and more power and bandwidth efficiency, in diverse environments. Among these, reliable and real time image communication is an important and attractive application. Obtaining this goal, along with optimal usage of all capabilities of heterogeneous networks, needs the use of some approaches to match the application with the underlying communication infrastructure as to maintain an optimum compromise among a number of contradicting factors of low bit rates, low complexity, low power, low delay, and high quality. Therefore, the implementation of real time and reliable image communication among the heterogeneous networks, while maintaining Quality of Service (QoS), is a challenging problem which needs the use of Joint Source-Channel Coding (JSCC) techniques [1, 2, 3, 4, 5, 6].

JSCC techniques, which jointly consider source coding and channel coding, improve the tradeoff between compression efficiency and robustness to increase Reliability and reduce Distortion, Complexity and Delay [7, 8, 9]. Multiple Description (MD) coding, Scalable Coding (SC), Unequal Error Protection (UEP) coding and Layered Multiple Description (LMD) coding are examples of JSCC techniques [10], used for image transmission over data networks.

Scalable coding addresses the problem of heterogeneous client bandwidths and dynamic network congestion by means of sequences of layers [13]. In SC an image is coded in a base layer and several enhancement layers. If only the base layer was encoded and transmitted first, basic image quality can be decoded in the receiver, and if the enhancement layers are also encoded and transmitted, a high quality image can be reconstructed. SC is useful for transmission over noisy and variable bit rate channels, since the more important layers can be better protected or the less important layers can not be transmitted [9]. MD coding, which addresses the problem of unreliable channels by means of independent descriptions, is source coding in which several descriptions of the source are produced such that various reconstruction qualities are obtained from different subsets of the descriptions [11, 13]. In MD coding, unlike multiresolution or layered source coding, the descriptions are independent and equally important; in other words, there is no hierarchy. Therefore, MD coding is suitable for packet erasure channels or networks without priority provisions [10]. Among these, Hybrid Techniques exploit the advantages of both layered codes and multiple description codes to achieve both robustness to unreliable channels and adaptivity to client bandwidth heterogeneity and network congestion. For example, an LMD system splits multiple descriptions into layers. The base layer (the highest important layer) descriptions are transmitted to low-bandwidth clients, while both base and enhancement layer descriptions are transmitted to high-bandwidth clients [12, 13, 14].

In this paper, a novel hybrid approach for Unequal Importance Image Communication (UIIC) over heterogeneous networks is explored. In this method, an image is divided into several layers of importance. Then, the low-rate base layer description is transmitted through a low-bandwidth, but robust
and more expensive channel, supporting delay-sensitive applications; while the high-rate enhancement layer description(s) are transmitted through a high-bandwidth, but high/variable-delay and cheap channel which does not support delay-sensitive applications. In the receiver, when the base layer description is quickly received, an acceptable quality image is reconstructed; and when the enhancement layer descriptions are received a high quality image can be reconstructed. Among this process, the base layer description can be strongly protected in the transmitter; also, in the receiver the quality of the image can be enhanced using different image enhancement algorithms. Such a method facilitates the process of real-time image distribution over heterogeneous networks not only for stationary users but also for mobile users since nowadays mobile devices support different standards for different applications. In fact, such a method paves the way for the optimum usage of present heterogeneous communication infrastructure for the adaptive and flexible requests of users.

The rest of this paper is organized as follows. In section II the general system description, in section III the image partitioning and protection methods and in section IV the implemented system and the simulation and practical results are presented. In continuation, in sections V and VI practical implementation approach and conclusion are explained, respectively.

II. UNEQUAL IMPORTANCE COMMUNICATION

Unequal Importance Image Communication is a JSCC scheme which uses diversity with different levels of importance and protection to create a reliable communication system. The main goal in this method is the effective usage of different existing communication infrastructures, by the optimal allocation and protection of source information, to increase quality, coverage, power and bandwidth efficiency, and the speed of communication, in diverse environments. In this approach, protection includes a variety of methods such as using different error control codes and modulation/detection techniques with different performances and using different levels of transmission power.

Fig. 1 shows the general block diagram of the system. In this system, the encoder partitions the source information into several layers with different rates, based on their importance. The different layers are sent over channels with different bandwidth and delay characteristics. The most important part of the information (base layer description) is sent through a robust and low-bandwidth channel, supporting delay sensitive applications (e.g. GSM), and the other part of the information (enhancement layer description(s)) is sent through a high-bandwidth and high/variable-delay channel. At the receiver, when the base layer description is quickly received an acceptable quality image is reconstructed, and when the enhancement layer description(s) (details) are received, the source can be reconstructed with higher quality.

In this project, with regard to the existence and availability of a variety of networks and communication systems in different places with today’s mobile communication devices, the target is the effective usage of different characteristics of this available and widespread heterogeneous networks in order to broadly and reliably distribute an image (as an important part of multimedia information) with high quality over wireless networks, while reducing the delay and cost of image communication. In fact, the main goal is the transmission of the most important part of information through a robust and low-bandwidth channel which supports delay-sensitive applications to reach a real-time image distribution system, particularly in mobile applications.

For example, consider personal notebooks and Personal Digital Assistants with the capability of access to different wired and wireless networks, such as WLANs, Bluetooth, GSM/GPRS and Ethernet LAN, with different bandwidth and delay characteristics. An effective usage of the heterogeneity among these networks can lead to attractive applications. For instance, consider the GSM network and WLANs with different characteristics. The GSM network has a low data rate, but it supports delay-sensitive applications such as voice communication requiring minimum delay during the transmission and generating symmetric traffic. On the other hand, WLANs have a high data rate, but the delay is high and variable. Also, the communication cost in GSM is higher than WLANs.

Accordingly, an effective hybrid coding system (Fig. 2) can split an image into different levels of importance (layers) and sends the base layer of description through a GSM network and the enhancement layer (or both the base and enhancement layers) description(s) through a WLAN (IEEE 802.11a/b/g). In this way, the user is able to reconstruct an image with acceptable quality in his mobile device, supporting different standards for different applications, quickly and cheaply in a wide coverage area (covered by GSM network) and in different situations either being stationary or mobile; also, he can reconstruct a higher quality image in many indoor and outdoor environments (covered by WLANs). The applications of this idea can be extended to wireless video, interactive games and chats and many other applications. To implement such a system two important questions arise: first, how to partition an image into different levels of importance? And second, how to create different levels of protection?

III. IMAGE PARTITIONING & PROTECTION

Data partitioning is designed to provide more robust transmission in an error-prone environment. Therefore, an effective unequal importance image coding system must be able to create different layers of descriptions of an image (based on their importance). In JPEG, as the most famous and ubiquitous image compression method, data partitioning can be performed by splitting the block of 64 quantized transform coefficients into partitions. For this purpose, JPEG exploits Discrete Cosine Transform, to capture the bulk of the image energy in a fraction of independent coefficients [9].

In natural images, dominated by a mixture of stationary low-frequency backgrounds and transient high-frequency edges, the lower partitions (low-frequency DCT coefficients) contain more critical information [12]. Therefore, to provide
In this system, protection can be performed by sending several equally important descriptions of the base layer through the high priority channel. For example, the base layer can be repeated several times or it can be protected by strong channel codes or higher power. Also, an MD coder can be used to transmit the enhancement layers. For this purpose, several JPEG based MD coders can be used [17, 18, 19].

IV. THE IMPLEMENTED UIIC SYSTEM

Fig. 6 shows our JPEG based unequal image importance communication system. In this system, image partitioning is performed using the spectral selection method discussed in the previous section. Then, the most important part of the information (the output of LPF) is sent through a GSM network, as a more robust, low-bandwidth channel with the ability of supporting delay-sensitive applications, and the other part of the information is sent through a WLAN (IEEE 802.11a/b/g), as a high-bandwidth and high/variable-delay channel.

In this system, the size of the image has a remarkable effect on the bandwidth, delay, and reconstructed image quality. Fig. 7 shows that when the size of the image is only greater than or equal to 128 pixels, $\text{PSNR} \geq 32 \, \text{dB}$ is achievable (for a 64*64 pixels image). Among these, if the DC coefficient of a 512*512 image is transmitted, the highest image quality can be reconstructed and in this case, the transmission of more coefficients is not useful. Therefore, it seems that a proper method, to obtain the best quality, is the transmission of the DC coefficients of a 512*512 image through a GSM network. Also, the AC coefficients of a smaller image size (e.g. 256*256 pixels) can be transmitted through a WLAN. In this case, the average of DC coefficients of each four adjacent blocks in a 512*512 image is estimated as the DC coefficient of each block in a 256*256 pixels image. This leads to a negligible error smaller than .01 dB (for Lena image). Therefore, using the transmission of DC coefficients of a 512*512 image not only leads to the reconstruction of a small size and high quality image (proper to display on many mobile devices such as cell phones and PDAs) but also, decreases image coding and decoding computations; which consequently, increases the power efficiency which is an important factor in wireless applications. In addition, a high quality image can be shown on bigger devices such as notebooks or desktops. Fig. 8 shows the result of this method.

On the other hand, Fig. 9 compares the total transmission time and achievable image quality in the case of using two different WLANs. Here, due to the unavailability of two GSM cards, the most important part of the information is sent through an IEEE 802.11a channel, as a more robust and faster network. And, the other part of the information (the output of filters 1 to 7) is sent through an IEEE 802.11b, as a slower channel. Fig. 10 shows the implemented system. In MATLAB, the total transmission time over IEEE 802.11a and b is in the order of 0.1 second, for example, 0.15 and 0.65 second, respectively.

V. PRACTICAL IMPLEMENTATION APPROACH

In this section, a very simple, almost optimum and highly compatible approach for implementation of the presented unequal importance image communication system is explained. In this method, only by changing the quantization table of JPEG compression standard (which has been allowed) the output of different filters in the filter bank is separated and coded. For example, to transmit only the DC coefficient of each block, the quantization coefficient for the DC coefficient remains constant; but, other quantization values increase so that they are changed to zero after quantization. Since, the maximum number of bits allocated to DC and AC coefficients are 11 and 10 bits, respectively, the quantization values can be changed to $a = 2^{11} + 1$ and $b = 2^{10} + 1$. Fig. 11 shows the two
examples of these quantization tables for coding the output of LPF and BF1.

VI. CONCLUSION

In this paper, a novel approach for reliable and real-time image communication over heterogeneous networks was presented. Such a system, by the effective use of the existing heterogeneity in today’s networks, facilitates the process of high quality image distribution among these networks not only for stationary users but also for mobile users. Also, it increases the coverage and bandwidth and power efficiency and reduces the delay and cost of image communication. Furthermore, this method, while using diversity to create a robust image communication, has the capability of using different protection techniques. In addition, its implementation is simple and it is highly compatible with JPEG, which is the most famous and ubiquitous image compression standard. Accordingly, since nowadays many mobile devices have access to several different wired/wireless networks, this method can play a significant role in broadly distributing images in diverse environments, quickly, efficiently and cheaply. Finally, the applications of this idea can be extended to wireless video, interactive games and chats and many other applications.

REFERENCES

Figure 5a. A comparison among different image partitioning methods and the impact of each DCT coefficient on the quality of Lena picture.

Figure 5b. A comparison among two represented image partitioning methods on two different images.

Figure 6. Our JPEG based UIIC system.

Figure 7. The effect of size of an image (Lena picture) on the reconstructed image quality.

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PSNR = 10 \log_{10} \left( \frac{64 \times 64 \text{ pixels}_{\text{original image}}}{64 \times 64 \text{ pixels}_{\text{reconstructed image}}} \right)
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Figure 8. The output of the UIIC system: a) Original image; b) reconstructed image by using DC coefficients; c) reconstructed image by using AC coefficients; d) reconstructed image by using the DC coefficients of an 512*512 pixels image and the AC coefficients of an 256*256 pixels image; e) reconstructed and shrunk image by using the DC coefficients of an 512*512 pixels image (for use on small mobile devices such as PDAs).

Figure 9. A comparison between the required transmission time of the output of each filter using two different WLANs (each o and + show the output of each filter).

Figure 10. The implemented UIIC system.

Figure 11. Two examples of new JPEG quantization table.