NETWORK-CONSCIOUS COMPRESSED IMAGE TRANSMISSION OVER BATTLEFIELD NETWORKS

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ABSTRACT

We introduce an image compression and transmission system for battlefield networks. The system is based on network-conscious image compression*, an approach to compression that does not simply maximize compression, but which optimizes overall performance when compressed images are transmitted over a lossy, packet-switched battlefield network. Using an Application Level Framing philosophy, an image is compressed into path-MTU-size Application Data Units (ADUs) at the application layer. Each ADU is independent of others and carries its own semantics, that is, each ADU is a self-contained unit possessing all information necessary for decoding and displaying the information within that packet. Each independent ADU can be delivered to the receiving application out-of-order, thereby enabling faster progressive display of the image. We combine network-conscious image compression with an embedded focusing feature to provide a system that can be used in battlefield scenarios such as telemedicine or intelligence gathering.* [a]

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1 INTRODUCTION

Traditionally, image compression algorithms have one primary objective: obtaining the minimum image size. We argue that, although minimum image size is an important factor, optimal image compression algorithms should also take into account that many images are to be transmitted over battlefield networks whose Quality of Service (QoS) will lose and reorder packets. Therefore, compression algorithms should not focus solely on achieving minimum image size; algorithms should be optimized to give the best performance when images are transmitted throughout the battlefield. Compression algorithms should take advantage of different QoS provided by the underlying transport protocol.

Our research investigates *network-conscious image compression*, a new concept that takes image transmission into consideration when designing image compression [9]. The principal idea behind network-conscious image compression is Application Level Framing (ALF) [3]. The application layer divides an image into path-MTU-size[b] pieces, called *Application Data Units* (ADUs), such that each piece is independent of all other pieces and carries its own semantics. That is, each ADU is a self-contained unit possessing all information necessary for its decoding and display at the receiver. Each ADU then can be delivered to the receiving application out-of-

[b]MTU (Maximum Transmission Unit) is the maximum frame size that a link layer can carry. A path-MTU-size packet can be transmitted over a network of links without the need for fragmentation and reassembly.

order, thereby enabling faster progressive display.

Our research demonstrates that with a combination of innovative transport protocols and only a small penalty in compression ratio, today's standard compression algorithms can be modified to provide better overall display of images, and hence performance, in a lossy packet-switched battlefield network.

We introduce an image compression and transmission system for battlefield networks that combines network-consciousness with focusing techniques. The focusing feature is embedded in the algorithm so that focusing on different portions of an image is made possible without decompression and recompression. This system is incorporated into our Network-Conscious Image Compression and Transmission System (NETCICATS) that have been used to test network-conscious image compression [8].

Section 2 briefly defines what a network-conscious compressed image is and describes NETCICATS. Section 3 describes the proposed system with focusing feature and explains how it might work in a real battlefield scenario. Finally, Section 4 provides a summary of the paper.

2 NETWORK-CONSCIOUS COMPRESSED IMAGES

A network-conscious compressed image is one that is encoded *not* to give the *smallest size* for a specified image quality but to give the *best (i.e., smallest) response time - image quality* combination to an end user retrieving the image over a packet-switched network. The basic characteristics of a network-conscious compressed image are as follows: It

- uses application level framing,
- provides progressive display and preferably uses a multilayered approach, and
- is adaptive to different user needs, and various networking conditions.

The key feature of network-conscious image compression is that it produces path-MTU-size, self-contained blocks (ADUs) that can be processed (compressed/decompressed) independent of each other. Therefore, when these blocks are transmitted over a lossy network, if received out-of-order, they can be processed immediately, giving better progressive display. This approach permits the use of a more efficient transport protocol that does not need to preserve order. The buffer requirements at the transport receiver for an unordered protocol are always less or equal to the buffer requirements at ordered protocols [10]. Furthermore, out-of-order delivery of ADUs reduces the jitter at the receiving application. In ordered transport protocols, ADUs that are received out-of-order must be buffered. When missing ADUs finally arrive, buffered ADUs are delivered as a group to the application. This approach makes the delivery of ADUs to the application more bursty. The burstiness may result in bottlenecks at the receiving application [7].

Another advantage of dividing an image into ADUs is that their transmission can be tailored to each ADU characteristic. Not all parts of image data are uniform and require the same QoS. For example, low frequency coefficients of a wavelet image (i.e., important data) require a reliable service. On the other hand, high frequency coefficients (i.e., less important data, details) may tolerate a certain level of loss. Therefore, having independent ADUs enables the use of different QoS such as reliability and priority for each ADU type.

Network-conscious compressed images also can easily adapt to different networking conditions. A network-conscious compressed image can be transmitted over a very low bandwidth lossy network as well as a high bandwidth reliable network. It can even be used, without modifications, in a multipoint communication, where each participant has different requirements.

At the University of Delaware, we have developed a system to empirically evaluate the network-conscious image compression. This system, called NETCICATS, transmits network-conscious compressed images over a lossy, low-bandwidth network [8]. The software consists of two main components: an image sender and an image receiver. The image sender is designed flexibly to allow a user to control (1)the quality and size of an image and (2)the transport service used to obtain the optimum performance from the available resources for that specific application.

Image quality and size are controlled by user-adjustable parameters such as the thresholding level (i.e., percentage of wavelet coefficients that are set to zero), quantization level (i.e., number of bits used for quantization), and the encoding method. Image quality can be measured both subjectively (by visualizing the image) and objectively (by PSNR–Peak Signal to Noise Ratio). The image receiver waits for image data and progressively displays it as it arrives.

The other components of the testing environment are SINCGARS radios (a PPP-link is also available) to simulate low bandwidth, lossy router software to introduce artificial yet controlled loss to the network, and transport protocols that provide a variety of services between TCP and UDP [4, 6].

We have also designed and implemented two algorithms that employ network-conscious compression: (1) GIFNCa [2] which is a modified version of standard GIF89a [1], and (2) a wavelet zerotree encoding based on the SPIHT algorithm [11].

3 AN IMAGE COMPRESSION AND TRANSMISSION SYSTEM FOR BATTLEFIELD NETWORKS

Typical battlefield scenarios include time-critical applications such as transmission of images for telemedicine or intelligence gathering. However, a battlefield's limited bandwidth and the lossy environment make image transmission difficult. Transmitting an average size image over SINCGARS radios (raw signaling rate 16 Kbps) whose effective bandwidth is less than 2 Kbps requires several minutes. However, in life or death circumstances decisions have to be made as fast as possible. It is crucial to transmit those parts of an image which will play the key role in the decision as soon as possible. That is, in a military scenario, it is not necessarily how quickly one can transmit a full image that is important, but how quickly one can transmit an image which is good enough for an informative decision to be made.

Two techniques are especially useful for this type of military application: progressive display and region of interest. *Region of Interest*, also called *focusing*, is a technique used to deliver higher reconstruction quality for important parts of an image. Focusing is especially useful in situations where having the same high quality for the whole image is not affordable for space or bandwidth limitations. A typical example application of this technique is medical image compression [13]. Typically regions of interest are decided before compression, and those parts of the image are compressed with higher reconstruction quality. Traditionally once the image is compressed, it is impossible to change the regions of interest without decompressing the compressed image and recompressing it with the new regions of interest properly defined.

We propose a battlefield image compression and transmission system that combines progressive display and focusing with the network-conscious image compression approach. The compression method is based on wavelet zerotree encoding [12]. Our research on zerotree encoding, progressive display, and focusing differs from previous studies in that we propose a flexible image compression technique and file format in which focusing is embedded inside the code along with the network-conscious image compression. That is, once an image is compressed, it contains all information necessary to do focusing on various parts of the image without the need for a decompression and recompression. Such an algorithm is especially useful in telemedicine where images of wounded soldiers are being transmitted to remote medical experts available for guidance in first aid and for deciding whether or not the patient should be transported to a hospital.

Here is how our system might work in such a scenario. An image of the wounded soldier is compressed and stored on a portable computer out on the battlefield. A connection back to the headquarters is established and image transfer begins. An initial rough image of the wound is displayed on the monitor back at headquarters. Then, as more data arrives, the image is progressively refined. When the medical expert has seen enough of the whole image and wants to focus on a certain region to have a better quality image, he/she identifies the region with the help of a mouse. The coordinates of this region are sent back to the computer on the battlefield. At this point, transmission of the remainder of the whole image is aborted with the help of the ADN-cancel feature, and only the focused image information is transmitted. ADN-cancel, an innovative transport layer service, allows cancellation of messages that have already been submitted ot the transport layer. The application specifies an Application Data Name (ADN) for each message, and can cancel the transmission of any message (or group of messages) by specifying its (their) ADN [5].

Wavelet zerotree encoding is based on the hypothesis that, at a given threshold level, if a wavelet coefficient at a coarse scale is insignificant, then all wavelet coefficients of the same orientation in the same spacial location at finer scales are likely to be insignificant [12]. The embedded zerotree encoding (EZW) by Shapiro and set partitioning in hierarchical trees (SPIHT) are two famous zerotree encoding methods. Both algorithms are highly state-dependent, and therefore susceptible to bit errors and packet losses. Even a single bit error can ruin the decoding process thereby destroying an entire image. In a battlefield environment where bit errors and packet losses are common, a robust compression algorithm which can tolerate packet losses is desirable. We have modified the SPIHT algorithm so that it produces path-MTU-size, independent packets. Since each packet is independent, this new algorithm is robust against packet losses.

In a compressed image file, there is a separate section for each of the zerotrees (i.e., a spacial location on the image) each of which can be independently compressed/decompressed. The compressed file contains the whole image with a high reconstruction quality. When an image needs to be transmitted, first the coarse image (i.e., the low-low frequency coefficients in wavelet transformation) is transmitted. This will allow the receiving application to initially display a rough image. Then each zerotree can be transmitted at any level of reconstruction quality. The more data read and transmitted for that particular zerotree, the better image quality will there be for that portion of the image.

There are three advantages to having such a format. First, the sending application can decide which portion of the image needs to be refined first (i.e., which portion is most important for the receiver) and transmit corresponding zerotrees first. Second, the sending application can decide to have different levels of image quality for different sections of the image and transmit corresponding zerotrees accordingly. Third, the receiving application can request more data for a particular section of the image to do focusing. The sending application will read the data from the compressed image file and transmit it.

This system is incorporated with NETCICATS (see Figure 1), where compressed images are stored on a server, and accessed by a client with an interface similar to familiar web browsers. The packets are routed through the Lossy Router, a modified IP router that simulates any of three loss models (Bernoulli, burst (2-Step Markov), or deterministic) and SINCGARS radios.

4 SUMMARY

Classical image compression algorithms are not optimally suited for lossy packet-switched battlefield networks. They are optimized for minimal image size only. However, minimum image size does not necessarily provide the best performance when those images are transmitted over lossy networks. The ordered-delivery requirement of these algorithms cause unnecessary delays at the receiving end.

We propose a new approach to image compression saying that the compression algorithms should not be optimized only to give the minimum image size; they should be optimized to give the best performance when they are transmitted over lossy networks. We have developed two compression algorithms that utilize this approach: a wavelet zerotree encoding algorithm and network-conscious GIF. We have also developed NETCICATS, a system to empirically evaluate our approach.

Initial experiments show that network-conscious compressed images perform better in terms of transmitting progressively displayed images over an unreliable network that loses and reorders packets when the underlying transport protocol allows out-of-order delivery.

By combining network-conscious image compression with a focusing technique, we came up with a wavelet zerotree based compression algorithm and a file format which allows focusing on-the-fly. The focusing feature is embedded into the algorithm so that focusing on different portions of an image is made possbile without decompressing and recompressing the file. This algorithm is especially useful in military applications such as telemedicine or intelligence gathering.

Our future study includes running experiments in this environment to collect and analyze extensive empirical data.

5 DISCLAIMER

The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either expressed or implied of the Army Research Laboratory or the U.S. Government.

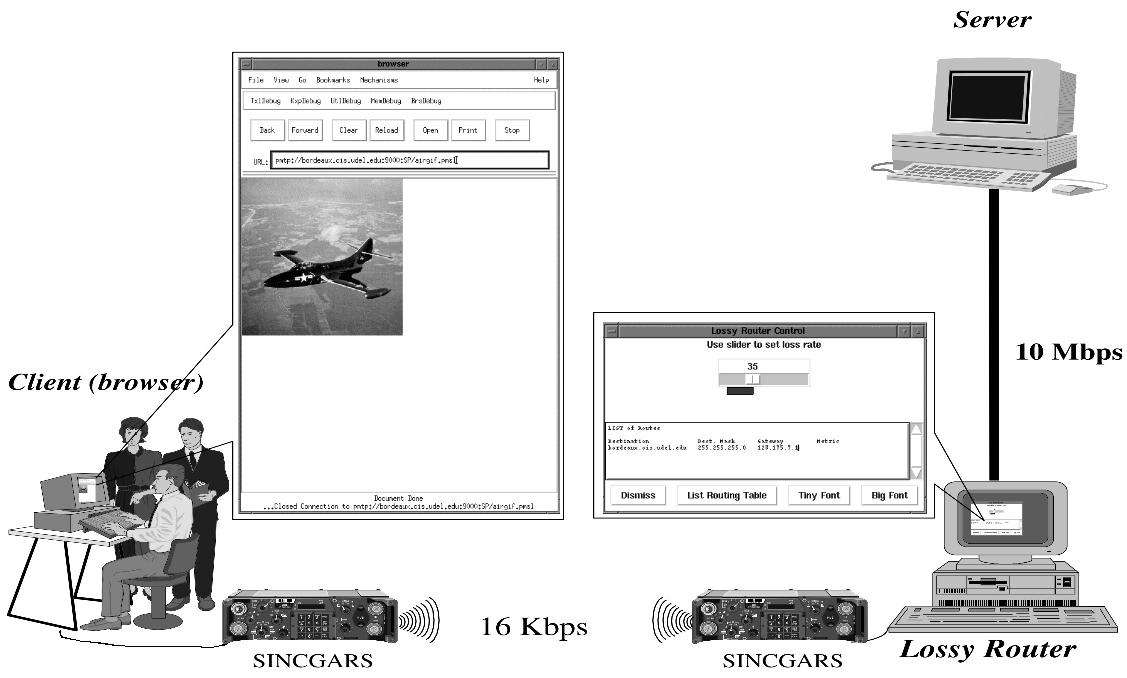

Figure 1: Testing Environment for Network-Conscious Image Compression Transmission with Focusing

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