Energy Efficient High Quality Image Transmission in Wireless Sensor Networks

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***Abstract* - A Simple Wavelet Compression (SWC) processing is proposed to maximize compression and minimize energy cost in WSN (Wireless Sensor Network). Most of the current work, utilize lossy image compression techniques to minimize the resource consumption. The lossy image compression technique reduces the size of the image to a great extent, however the quality of the image being reproduced needs appreciation. The existing work presented, an improved polyomines lossless compression technique, which increases the quality of image at receiving end of the wireless communication by reducing the Peak to Signal Noise ratio and mean square error. In Wireless Sensor Networks, reducing transmission energy consumption is one of the important critical issues.**

In this paper, we propose a novel Energy Efficient High Quality Image Transmission scheme (EEHQIT) to achieve energy efficient image transmissions in WSNs. EEHQIT scheme is compelling due to its ability of saving individual power consumption over multiple sensors by spreading total transmission consumption. Individual packets describing an embedded wavelet-encoded image exhibit a significantly unequal contribution towards image quality. By leveraging this fact we develop a strategy of appropriately selecting the number of interactive sensors for each packet transmission in order to achieve the highest possible image quality with minimal transmission power consumption. Experimental results show that our proposed mechanism can provide about 2dB higher image quality under the same power budget compared with other transmission approach. Simulation results show up to 85% reduction in the total power consumption achieved by using the proposed strategy.

Keywords: Wireless communication, Image compression, interactive transmission, image quality.

I. Introduction

Large-scale networks of sensors with wireless communication capability have drawn the attention of researchers for the last few years. Most of the applications are centered towards harvesting information from the physical environment, performing a simple processing on the extracted data and transmitting it to remote locations. In general, most of the applications require a small bandwidth demand and usually transmission delay is not a major concern. These devices normally are equipped with multi-hop capabilities, self-healing, automatic-management and self configuration. These attributes make WSNs suitable for a wide range of application ranging from home automation, surveillance to industrial process control. The idea of including image processing capability into the sensor mode not only will enhance the existing applications but also will enable new ones.

The 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, 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.

The usual method for transmitting images over the Internet is to first compress the images using a lossy scheme such as JPEG, and then to transmit them across the intrinsically lossy Internet using the lossless TCP/IP protocol. JPEG and related lossy schemes are very sensitive to bit errors and hence require lossless transmission. The price paid for lossless transmission over a lossy medium is excessively lengthy transmission times due to retransmissions of lost packets. A more efficient means of transmitting the data is via some form of redundant transmission (forward error correction) which will make serious transmission errors unlikely. Redundancy must be applied selectively, however, since the addition of redundancy increases the amount of information to be transmitted. Lossless transmission schemes are even more problematic for Internet video broadcasting. Retransmission is impractical with broadcasting because the receivers will not in general experience the same losses. A broadcaster attempting to respond to all of these different losses will quickly be overwhelmed. Again, what we need to cope with packet losses is some form of forward error correction.

II. Related Works

Wireless Multimedia Sensor Network (WMSN) is defined as a network of wireless embedded devices that allow retrieving video and audio streams, still images and scalar sensor data from the physical environment which can be understood as a convergence between the concept of WSN and distributed smart cameras [3].Literature survey in [1], [2], [4] addressed various issues regarding the challenges faced by research community in realizing WMSN. Even with the availability of CMOS camera which is low cost, low power and small form factor, current WSN constraints still prohibit the implementation of effective and efficient multimedia data into it. A new paradigm is needed in order to realize WMSN in the aspect of hardware design, algorithms, protocols and techniques to deliver multimedia content over a large-scale network given the nature of the wireless sensor network which has a very tight resource constraint.

The early research efforts in wireless sensor networks did not investigate the issues of node collaboration, focusing more on issues in the design and packaging of small, wireless devices [5], more recent efforts (e.g. [6], [7]) have considered node collaboration issues such as data “aggregation” or “fusion”. Our approach of distributed image compression falls within the domain of techniques that apply the concept of network processing, i.e. processing in the network by computing over the data as it flows through the nodes. It is worth noting that current aggregation functions (e.g., “maximum” and “average” [7]) are limited to scalar data. Our approach can be viewed as an extension to vector data aggregation.

Previous distributed signal processing/compression problems (e.g. [8], [9]) exploit correlations between data at close-by sensors in order to jointly compress or fuse the correlated information resulting in savings in communication energy. In parallel distributed computing theory [10], a problem (or task) is divided into multiple sub-problems (or sub-tasks) of smaller size (in terms of resource requirements). Every node solves each sub problem by running the same local algorithm, and the solution to the original problem is obtained by combining the outputs from the different nodes. Our approach to the design of distributed image compression is similar in concept, in that we distribute the task of image encoding/compression to multiple smaller image encoding/compression sub-tasks. However, a key difference is that distributed computation theory typically focuses on maximizing the speed of execution of the task while our primarily concern here is reducing the total energy consumption subject to a required image quality. Thus, our proposed approach of image compression intersects with the literature on lossy and lossless compression, which primarily focuses on polyomino technique.

W. Yu Z. Shinoglu and A.Vetro. in [11] proposes an optimized joint source channel coding (JSCC) scheme to achieve minimized total distortion for multiple images over lossy channels simultaneously. The layer-based dependency as well as distortion reduction expectation is well modeled, and combined total distortion is minimized subject to total rate constraint. Hamzaoui et al. survey recent advances in forward error correction (FEC) based scalable image coder in [13], and propose a local-search-based rate-distortion optimization solution. Li et al. in research [14] develop a real-time link layer retry limit adaptation algorithm for robust video streaming over 802.11-based wireless networks. Multiple video layers are unequally protected by different link layer retry limits. van der Schaar and Turaga in [12] propose cross-layer optimized packtization and retransmission strategies for delay sensitive video delivery over WLANs.

The cross-layer optimization problem is formulated as distortion minimization given delay constraints, and significant multimedia quality gain is reported by packtization and retransmission optimization. The aforementioned works are mainly delaydistortion or rate-distortion optimization algorithms suitable for general wireless networks; it is hard to be directly used in WSNs due to the limited energy rather than bandwidth resource in WSNs.

III. Energy Efficient High Quality Image Transmission in Wireless Network

3.1. Lossless Image Compression

There are two types of image compression: lossless and lossy. After decompression the original image is recovered. Compressing an image is significantly different than compressing raw binary data. The general purpose compression is used to compress images, but the result is less than optimal. This is because images have certain statistical properties which can be exploited by encoders specifically designed for them. This also means that lossy compression techniques can be used in this area.

An integer-to-integer wavelet transform produces an integer-valued transform from the grey-scale, integer-valued image [11]. Since n loops in Bit-plane encoding reduces the quantization error to less than $T0/2^n$, it follows that once 2^n is greater than T0, and there will be zero error. In other words, the bit-plane encoded transform will be exactly the same as the original wavelet transform, hence lossless encoding is achieved Lossless compression involves with compressing data which, when decompressed, will be an exact replica of the original data. This is the case when binary data such as executables, documents etc. are compressed. They need to be exactly reproduced when decompressed.

3.2 Error Metrics In Wavelet based image compression

Two of the error metrics used to compare the various image compression techniques are the Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR). The MSE is the cumulative squared error between the compressed and the original image, whereas PSNR is a measure of the peak error. The mathematical formulae for the two are

$$MSE = \frac{1}{MN} \sum_{y=1}^{M} \sum_{x=1}^{N} [I(x,y) - I'(x,y)]^2 \quad +MN$$

PSNR = 20 * log10 (255 / sqrt(MSE))

where I(x,y) is the original image, I'(x,y) is the decompressed image and M,N represents dimensions of the images. A lower value for MSE means lesser error, and as seen from the inverse relation between the MSE and PSNR, this translates to a high value of PSNR. Logically, a higher value of PSNR is good because it means that the ratio of Signal to Noise is higher.

The signal is the original image, and the noise is the error in reconstruction. It is highly required to evaluate a compression scheme having a lower MSE (and a high PSNR).

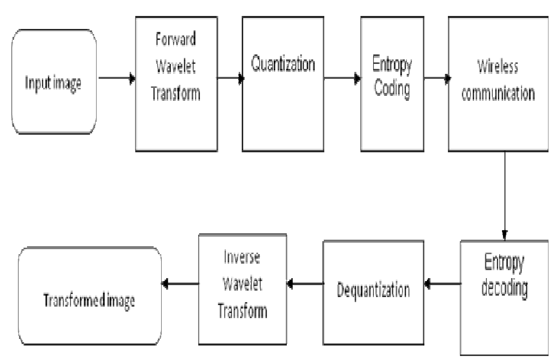

Fig 1: Image transmission

3.3 Wavelet Image Compression

Wavelet based image compression introduces no blocky artifacts in the decompressed image. The decompressed image is much smoother and pleasant to eyes. We can also achieve much higher compression ratios regardless of the amount of compression achieved. By adding more and more detail information we can improve the quality. This feature is attractive for what is known as progressive transmission of images. Another compression scheme developed for image compression is the lossy image compression scheme (fig 1).However the lossy image compression is very complex and time consuming.

The filter components are reduced their size by half either by rejecting the even or odd samples thereby the total size of the original signal is preserved. The low pass filter component retains almost all distinguishable features of the original signal. And the high pass filter component has little or no resemblance of the original signal. The low pass component is again decomposed into two components. The decomposition process can be continued up to the last possible level or up to a certain desired level. As the high pass filter components have less information discernible to the original signal, we can eliminate the information contents of the high pass filters partially or significantly at each level of decomposition during the reconstruction process. It is this possibility of elimination of the information contents of the high pass filter components that gives higher compression ratio in the case of wavelet based image compression.

3.4 Energy Efficient High Quality Image Transmission scheme

In this paper, we propose image transmission scheme driven by energy efficiency considerations in order to be suitable for wireless sensor networks. Wavelet image transform provides data decomposition in multiple levels of resolution, so the image can be divided into packets with different priorities, the packets are ready to be sent.

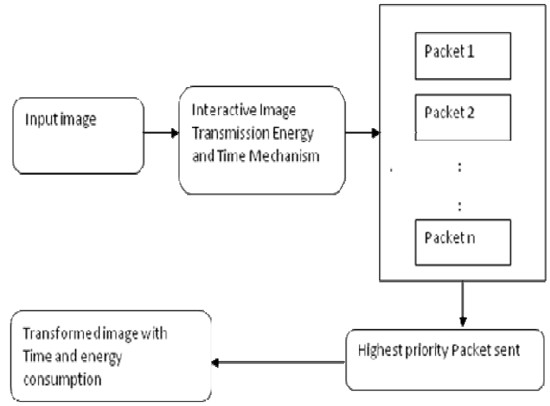

Fig 2: Interactive Image Transmission Energy and Time Approach

Figure 2 shows the diagrammatic representation of our proposed Interactive Image Transmission Energy and Time Approach. The source sensor transmits the packets starting by those with the highest priority, and then continues with those of the next lower priority, and so on. Since it is not mandatory to receive all the priority levels at the sink, except the basic level 0, in order to play out a version of the image, packets of subsequent priorities are only forwarded by intermediate nodes if their battery state-of-charge is above a given threshold. This choice is motivated by the scarce energy in the context of sensor networks. In fact, the hop-by-hop transmission is handled as reliable, i.e., the data packet is always acknowledged and retransmitted if lost, whereas the end-to-end transmission is handled as semi-reliable, i.e., the intermediate node decides to forward or discard a packet according to the battery's state-of-charge and the packet's priority. This is carried out using a threshold-based drop scheme where each of the p priorities is associated to an energy level.

A node can discard packets even if it has sufficient energy to forward them, if it knows that a node further down the path has an insufficient amount of energy. Of course, the node does not initially know the state-of-charge of the other nodes. This knowledge is gradually obtained from received acknowledgment packets. Thus feedback is used to report the lowest energy level currently available in others nodes. The delay induced by the feedback is proportional to the distance between the concerned nodes.

IV. Result and Discussions on the Performance of Energy Efficient Image Transmission scheme

In this section, we apply the energy consumption models to evaluate and compare energy performance of image transmission schemes in various scenarios. A monochrome image of 128X128 pixels, is used as a test image. This one is 8 bits per pixel originally encoded. That means a data length of 16394 bytes, including the image header of 10 bytes. Numerical values adopted for the input parameters of energy models are described below. Then, we present the results of numerical application.

To get a reference, we evaluated the consumed energy by transmitting the whole image (37249 bytes) reliably without applying WT or compression algorithms. In the following, we call that the "the original scenario". The amount of energy dissipated to transmit the original image is 15J per hop. Afterwards, we applied WT once and then twice without compression. When WT is applied once, we obtained a resolution 0 of 4106 bytes and a resolution 1 of 12288 bytes. Similarly, when WT was applied twice, we obtained 1034, 3072 and 12288 bytes for resolutions 1, 2 and 3 respectively. We computed the average energy consumption to transmit the image for scenario (Interactive Image Transmission Energy and Time WT). Figure 3 shows the average consumed energy per node as a function of the number of intermediate nodes. We see that the consumed energy when WT is applied is clearly lower compared to the case without WT.

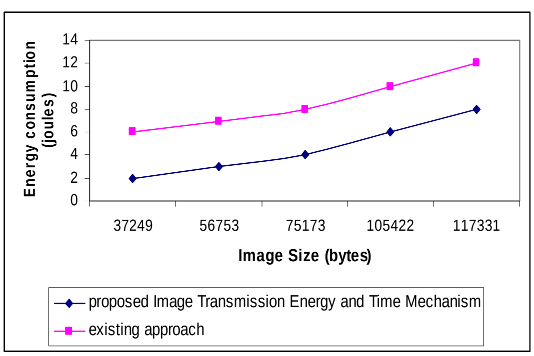

Fig 3: Image size Vs energy Consumption

Figure 3 shows the comparison of our proposed Interactive Image Transmission Energy and Time Mechanism with existing approach. For simulation the image size is taken as bytes. There are five images taken for experimentation (37249, 56753, 75173, 105422, 117331). As the image size increases, energy also gets increased. When compared to existing approach our proposed Interactive Image Transmission Energy and Time approach consumed lower energy.

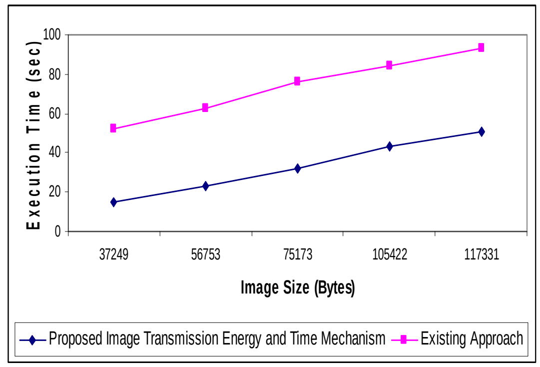

Fig 4: Image size Vs Execution Time

Figure 4 depicts the execution time for transmitting image by using our Interactive Image Transmission Energy and Time approach. For experimental works, the image size is taken as bytes. Execution time is measured in terms of seconds. Here five images are taken for simulation (37249, 56753, 75173, 105422, and 117331). As the image size increases, execution time also gets increased. By the comparison of our approach with existing work, proposed Interactive Image Transmission Energy and Time Mechanism have better performance.

V. Conclusion

The proposed work presented an improved wavelet based inductive methods for lossless image compression, lossy image compression and the wavelet image compression which can be effectively deployed in the transmission of wireless communication. The proposed scheme has selected two parameters of the JPEG image compression algorithm to vary, and gives the results of modifying the parameters on quality of image, and computation and communication efficiency with respect to energy utilization.

This paper has presented image transmission scheme driven by energy efficiency considerations, based on wavelet image transformation also to achieve with high quality transmission. It achieves high-energy efficiency and time consumption. The results obtained by our analytical model of the energy and time consumption are promising since the time and energy savings are significant and communication protocols are of low complexity. The energy savings is about 85% in our Interactive Image Transmission Energy and Time Mechanism, with a guarantee for the image quality to be lower-bounded. Consequently, we argue that our proposals are suitable for WSN.

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