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Image compression technique with low power consumption for wireless sensor networks

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***Abstract*— In the last years, wireless sensor networks (WSNs) have gained increasing attention from the research community. Since the main characteristic of such networks is nodes with scarce resources and sensor nodes are generally powered by small batteries as an energy resource, the multimedia data transfer services will impose severe demands on the battery resources as well as the bandwidth of the wireless network. Therefore, the critical aspects to face concern how to optimize the energy consumption of nodes, so that the network lifetime can be extended to reasonable times. In this paper we break down the energy consumption for the sensor node, and discuss the main directions to energy conservation in WSNs. To address this problem, an energy efficient image compression technique which is based on the Discrete Wavelet Transform (DWT) using the lifting scheme is considered. Performance studies indicate that the proposed technique enabling significant reductions in computation energy needed, with minimal degradation in image quality.**

***Keywords*— Image compression technique, Low energy consumption, Discrete wavelet transform, Wireless sensor networks.**

I. INTRODUCTION

A wireless sensor network (WSN) is a set of very small, inexpensive, resource constrained devices, called sensor nodes, ranging from a few dozen to several thousand elements. Each node is an embedded system with attached sensors that can process, exchange sensed-data, as well as, communicate wirelessly among themselves to perform various tasks [1]. Figure 1 show an example of a typical sensor node structure, in which, *Micro Controller Unit (MCU)* is the unit that is responsible for controlling all activities of node and executing communication protocols. The sensor module includes sensors attaching to the node and the RF receiver for wireless data communication. Depending on the specific application, sensor nodes may also include additional components which are optional such as a location finding system to determine their position, a mobilizer to change their location or configuration.

The development of such networks was originally motivated by military applications such as battlefield surveillance. However, wireless sensor networks are now used in many civilian application areas, including environment and habitat monitoring, healthcare applications, home automation, and traffic control. In these applications, the sensor network could help the engineers to monitor the system by periodically collecting data about the system's modules.

The data collected by sensors is transmitted to a special node equipped with higher energy and processing capabilities called "Base Station" (BS) or "sink". The BS collects filters and aggregates data sent by sensors in order to extract useful information. One of the major challenges in enabling image transfer services will be the need to process and wirelessly transmit very large volumes of data. This will impose severe demands on the battery resources of image-based applications as well as the bandwidth of the wireless network. Typically, images are compressed in order to save consumed energy.

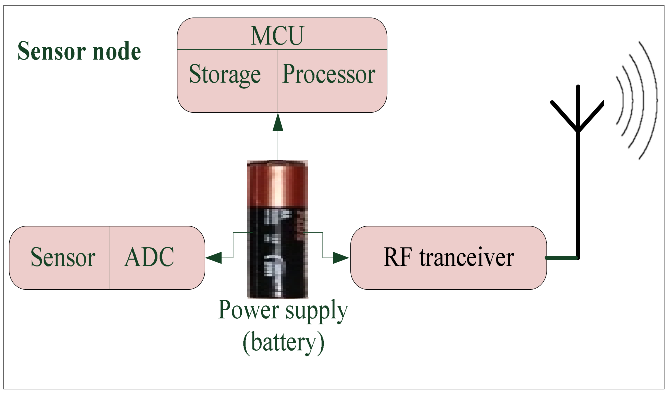


Fig. 1. A typical sensor node structure

In this context, image transmission improvement over WSN is mainly done by the data reduction in order to reduce the number of bits needed to represent an image by removing the spatial and spectral redundancies, thus reducing the energy consumption. In this paper, we concentrate on the problem of efficiently compressing images in a resource-constrained multi-hop wireless network. We have made a first attempt at the design and performance evaluation of the image compression scheme in such networks. By exploiting the characteristics of the Discrete Wavelet Transform (DWT), we propose a now image compression scheme based on lifting scheme subject to a specific image quality requirement. In particular, we propose an improved version of wavelet image compression and investigate their performance in terms of energy consumption and image quality in multihop wireless sensor network. Simulation results show that our approach optimizes the computational energy comparable to the standard algorithm.

II. ENERGY EFFICIENT DATA COMPRESSION

For multimedia-based applications, the image compression is a very popular research topic in the field of multimedia processing. Its goal is to store an image in a more compact form. Among a variety of image compression algorithms, the wavelet-based coding is a commonly used for still image compression. Wavelet-based schemes are more robust under transmission and decoding errors, and also facilitate progressive transmission of images. Theoretically, the **D**iscrete **W**avelet **T**ransform (DWT) is a 2 dimensional separable filtering operation across rows and columns of input image. The DWT is based on the multi-resolutions concept which reduces the amount of processed data and therefore would facilitate a progressive image's transmission. The DWT is achieved by applying a **L**ow-**P**ass **F**ilter (LPF) followed by a **H**igh-**P**ass **F**ilter (HPF) on each pixel, line by line and then column by column. At the end of this process, we get four sub-bands: low-low (LL_1), low-high (LH_1), high-low (HL_1) and high-high (HH_1) [2]. The low-pass sub-band represents a down sampled of the original image. The high-pass sub-band represents residual information of the original image, needed for the perfect reconstruction of the original set from the low-resolution version. Specifically, the LL_1 sub-band can be transformed again to form LL_2, HL_2, LH_2, and HH_2 sub-bands, producing a two-level wavelet transform. The information of LL_2 is used for the third level transform as illustrated in Figure2.

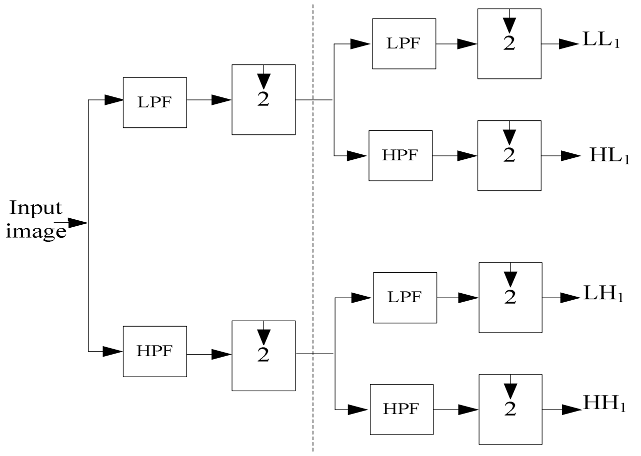


Fig. 2. 2-D DWT applied once

III. THE LIFTING-BASED DWT ALGORITHM

Usually the Lifting-based DWT requires less computation compared to the convolution-based approach. However, the savings depend on the length of the filters. During the lifting implementation, no extra memory buffer is required because of the in place computation feature of lifting. This is particularly suitable for the hardware implementation with limited available on-chip memory. Many papers proposed the algorithms and architectures of DWT [3], [4], [5], but they require massive computation. In 1996, Sweldens proposed a new lifting-based DWT architecture, which requires half of hardware compared to the conventional approaches. The discrete wavelet transform factoring into lifting scheme is represented as [6]:

$$\tilde{P}=\begin{bmatrix}1 & a(1+z^{-1})\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ b(1+z^{-1}) & 1\end{bmatrix}\begin{bmatrix}1 & c(1+z^{-1})\\ 0 & 1\end{bmatrix}\begin{bmatrix}1 & 0\\ d(1+z^{-1}) & 1\end{bmatrix}\begin{bmatrix}\zeta & 0\\ 0 & 1/\zeta\end{bmatrix} \quad (1)$$

Where a , b , c and d are the coefficients of lifting scheme, and ζ and $1/\zeta$ are scale normalization factors.

The architecture based on lifting scheme consists of a series of split, predict and update steps that modify, or lift, one set of samples to be used in the next step as shown in Figure 2.

The split step separates odd and even samples, and the predict step predicts values in the odd set, as follows:

$$H^1(i,j)=x(i,2j+1)+a(x(i,2j)+x(i,2(j+1))) \quad (2)$$

The update step uses the new wavelet coefficients in the odd set to update the even set producing "smooth" or "scaling" coefficients:

$$L^1(i,j)=x(i,2j)+b(H^1(i,j)+H^1(i,j-1)) \quad (4)$$

The high-pass and the low-pass output samples are stored into the registers where the odd (even) samples of the input data were originally stored at the beginning of the computation.

$$H^2(i,j)=H^1(i,j)+c(L^1(i,j)+L^1(i,j+1))$$
$$L^2(i,j)=L^1(i,j)+d(H^2(i,j)+H^2(i,j-1)) \quad (5)$$

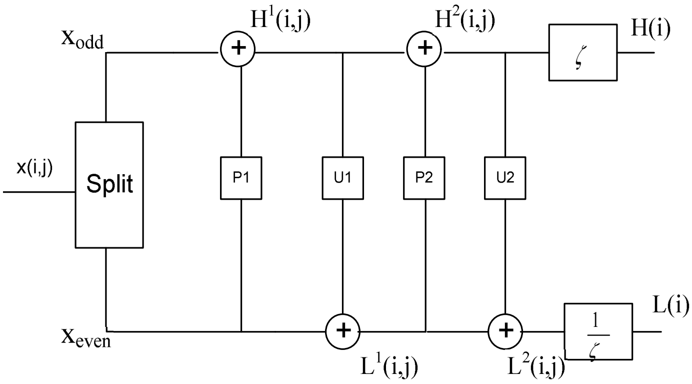


Fig. 3. The architecture of 9/7 1-D DWT based on lifting scheme

IV. THE MODIFIED 9/7 2-D DWT ALGORITHM

In this section, we propose an image compression technique based on lifting scheme able to provide energy efficiency considerations in order to be suitable for wireless sensor networks. This technique attempts to minimize computation energy by reducing the number of arithmetic operations and memory accesses. We use wavelet coefficients to eliminate a large number of samples from consideration in the image compression process. The purpose exploits the energy concentration of the decomposed image. Figure 4 illustrates the distribution of wavelet coefficients after applying a 1-D DWT to the 256×256 Photograph image. We notice that the high-pass coefficients are generally represented by small integer values. Consequently, the filtering step can compact the significant coefficients in the L_i sub-band. Based on the numerical distribution, we can estimate the high-pass coefficients to be zeros and hence avoid computing them resulting in a minimum image quality loss.

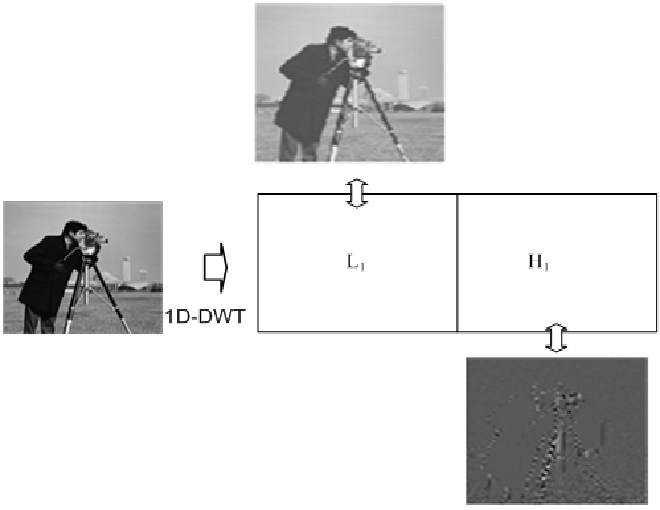


Fig. 4. The Wavelet coefficients concentration after wavelet transform through 1-D DWT

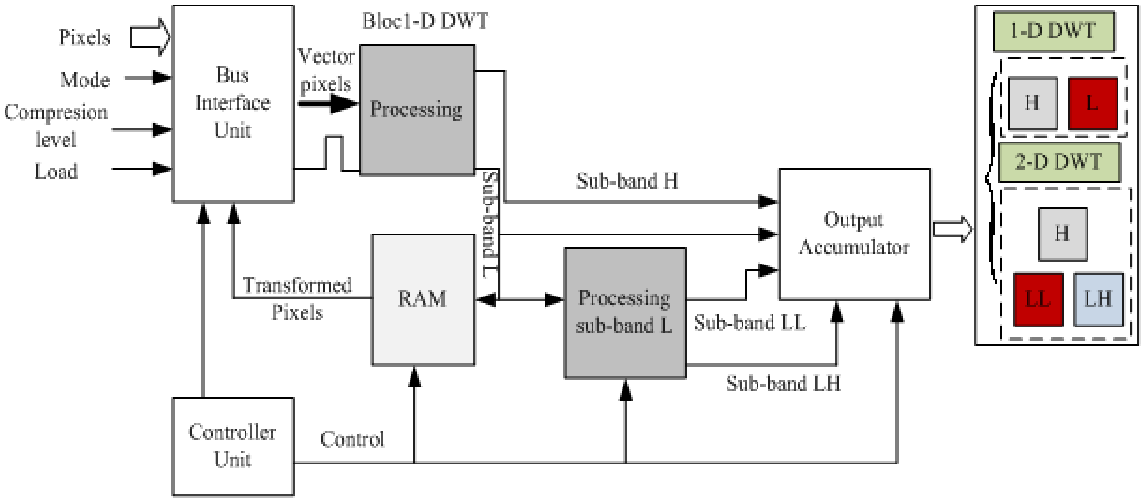
Based on the estimation technique, we have developed our approach attempting to conserve energy by avoiding the computation of high-pass coefficients. The proposed technique attempts to conserve energy by skipping the least significant sub-band. After executing a 1-D sub-band decomposition, the low-pass sub-band (L_1) resulting is decomposed in the vertical direction, leading to LL_1 and HL_1 sub-bands. The high-pass sub-band (H_1) is skipped. Then, the first decomposition level results the LL_1, HL_1, and H_1 sub-bands. After one transform level, the image is then processed by applying the 2-D sub-band decomposition to the LL_i sub-band while skipping the high-pass sub-band (H_i) in the vertical direction. The proposed technique is implemented by making specific modifications on the wavelet transform [7].

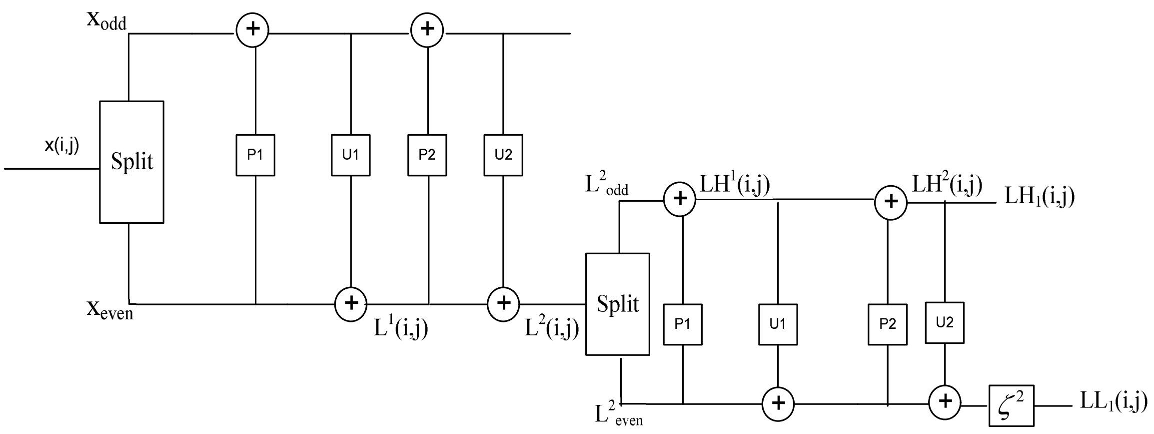
(a)

According to the architecture of 9/7 1-D DWT based on lifting scheme, the architecture of the modified 9/7 2-D DWT based on lifting scheme can be derived and shown in Figure 5. In this case, we proposed a high-efficient architecture for the even and odd parts of 1-D DWT based on lifting scheme to skip the sub-band (H_i) which is least significant (Figure 4), making it the best candidate for elimination during each compression level [8] [9]. The low-pass sub-band (L_i) resulting from the horizontal direction is further decomposed in the vertical direction, leading to LL_i and HL_i sub-bands. Then, the first SHPS level results the LL_1, HL_1, and H_1 sub-bands. After one transform level, the image is then processed by applying the 2-D sub-band decomposition to the LL_i sub-band while skipping the high-pass sub-band (H_i) in the vertical direction. This process can be repeated up to any level.

The sub-bands generated through the first compression level are represented as follows:

$$\begin{aligned}
LH^{1}(i,j) &= L^{2}(2i+1,j) + a(L^{2}(2i,j) + L^{2}(2(i+1),j)) \\
LL^{1}(i,j) &= L^{2}(2i,j) + b(LH^{1}(i,j) + LH^{1}(i-1,j)) \\
LH^{2}(i,j) &= LH^{1}(i,j) + c(LL^{1}(i,j) + LL^{1}(i+1,j)) \\
LL^{2}(i,j) &= LL^{1}(i,j) + d(LH^{2}(i,j) + LH^{2}(i-1,j)) \\
LH_{1}(i,j) &= LH^{2}(i,j) \\
LL_{1}(i,j) &= LL^{2}(i,j) \times \zeta^{2}
\end{aligned} \tag{6}$$





(b)

Fig. 5. (a) The proposed hardware architecture for the adopted technique; (b) the architecture of the proposed technique based on lifting scheme

V. MODELING ENERGY CONSUMPTION USING THE WAVELET TRANSFORM

A model of energy consumption for the wavelet transform is defined by Lee and Dey [10]. This model was developed by decomposing the overall process in elementary instructions, and determining how often these instructions were executed when the CDF 9/7 DWT is applied. Indeed, for each pixel of the original image, the low-pass filter requires 8 shifts (S) and 8 additions (A), while the high-pass filter requires 4 additions and 2 shifts. The energy required for the decomposition low pass / high pass can be defined by the number of operations. This energy is called "computational load". In addition, using the lifting scheme, each pixel must be read and written twice in a memory. We consider the “data access load” is the number of read and write operations. Assuming that the input image size is of M - N pixels and that the image is decomposed into p resolution level, then the 2D-DWT is iteratively applied p -1 levels. Since the image is divided into 4 sub-bands in each transform level, the total computational energy for this process can be computed as a sum of the computational load and data-access load as follows:

$$\begin{aligned} E_{9/7DWT} &= MN(10S+12A+2R+2W).\sum_{i=1}^{p-1}(\frac{1}{4})^{i-1} = \\ &= MN(10S+12A+2R+2W).\sum_{i=0}^{p-2}(\frac{1}{4})^{i} \qquad (7) \\ &= \frac{4}{3}MN(10S+12A+2R+2W)\left[1-4^{-(p-1)}\right] \end{aligned}$$

where S, A, R_{mem}, and W_{mem} represent the energy consumption for shift, add, read, and write of one-byte instructions, respectively

VI. RESULTS AND DISCUSSIONS

In this section, we report on experiments conducted to evaluate the energy savings made possible by using the proposed technique. In particular, we report on the savings in computational energy using the modified 9/7 2-D DWT, and discuss their impact on image quality. We use the 256×256 size Photograph image sample for the experiments reported in this section.

V.1. Effects of computational energy

In this study, we report on computation energy saving generated by proposed technique as described in the previous section, and compare the results with the 9/7 DWT algorithm. Using the modified 9/7 2-D DWT, after the wavelet decomposition 1-D, the L_1 sub-band resulting from the low pass filter is decomposed along the columns, leading the LL_1, HL_1, and H_1sub-bands. The sub-band H_1 is not computed in the vertical decomposition in each decomposition level. This leads to a gain of about:

$$\underbrace{\frac{1}{4}MN\ (8A+8S)}_{LH}+\underbrace{\frac{1}{4}MN\ (4A+2S)}_{HH}=\frac{1}{4}MN\ (12A+10S) \qquad (8)$$

Therefore, using the proposed approach, the total data-access load and computational load are given by:

$$\begin{aligned} C_{SHPS} &= \frac{3}{4}MN\ (12A+10+2R+2WS)\sum_{i=1}^{E}(\frac{1}{4})^{i-1}+ \\ &\quad MN\ (12A+10S+2R+2W)\sum_{i=E+1}^{p-1}(\frac{1}{4})^{i-1} \\ &= \frac{3}{4}MN\ (12A+10S+2R+2W)\sum_{i=0}^{E-1}(\frac{1}{4})^{i}+ \qquad (9) \\ &\quad MN\ (12A+10S+2R+2W)\sum_{i=E+1}^{p-2}(\frac{1}{4})^{i} \\ &= MN\ (10S+12A+2R+2W)\left[1-4^{-(p-1)}\right] \end{aligned}$$

From Eqs. (7) and (9), we have determined the total gain which is given by :

$$\begin{aligned} Gain &= \frac{4}{3} MN(12A+10s+2R+2W)\left[1-4^{-(p-1)}\right] - \\ &\quad MN(12A+10S+2R+2W)\left[1-4^{-(p-1)}\right] \\ &= \frac{1}{3} MN(10S+12A+2R+2W)\left[1-4^{-(p-1)}\right] \end{aligned} \tag{10}$$

Table 1 represents the computation energy savings obtained using the modified 9/7 2-D DWT, as normalized to the 9/7 DWT transform. We notice that when the proposed technique is applied through compression level 1, the energy savings is 25% less compared to the 9/7 DWT transform. At compression level 2, the proposed technique yields 31.25% energy savings at nominal loss in image quality. In addition, the purpose may optimize communication energy. This point is achieved by minimizing the information being transmitted over the wireless channel.

TABLE I. EFFECTS OF VARYING COMPRESSION LEVELS ON COMPUTATIONAL ENERGY

Compression levels	Computational energy saving (%)
p-1=1	$\frac{1}{4}MN(12A+10S+2R+2W)=25$
p-1=2	$\frac{5}{16}MN(12A+10S+2R+2W)=31.25$
p-1=3	$\frac{21}{64}MN(12A+10S+2R+2W)=32.81$
p-1=4	$\frac{85}{256}MN(12A+10S+2R+2W)=33.2$

V.2. the trade-off between the energy consumption and the image quality

The computation energy of the proposed technique is associated with a loss in the image quality. The results indicate that one can get improvement in PSNR using the modified 9/7 2-D DWT over 9/7 DWT. In particular, as we decrease the quantization level we get more PSNR difference compared to 9/7 DWT technique, which is clearly visible in Figure 6.

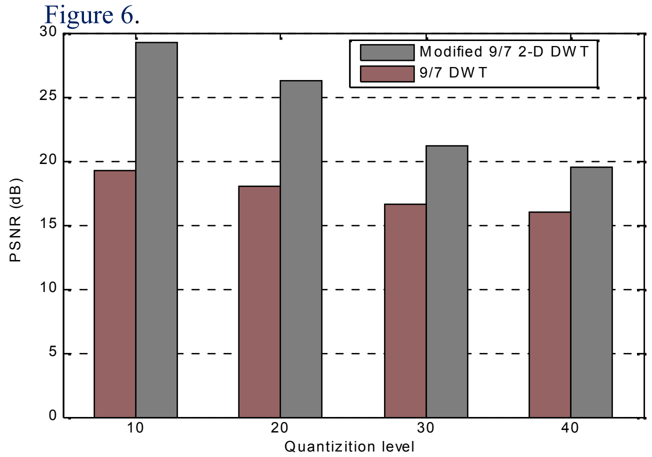
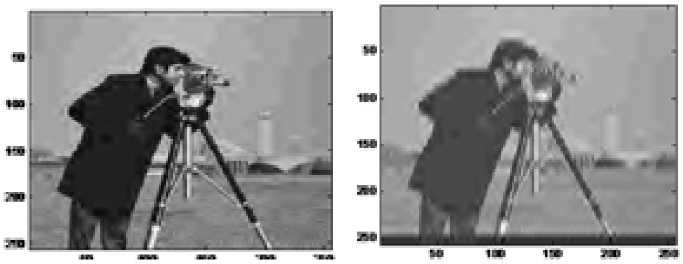


Fig. 6. Improvement in PSNR using proposed techniques at the third compression level over 9/7 DWT

Thus, when applying the proposed technique and 9/7 DWT technique at different compression levels, different trade-offs can be obtained between the image quality and the energy expended. The trade-off between computation energy and image quality when processing and transmitting an image is determined by the wireless application and the battery's state-of-charge.

In the Figure 7, we present a comparison between both 9/7 DWT and the modified 9/7 2-D DWT technique. Despite, the better image quality provided by 9/7 DWT, the result of the proposed technique is still acceptable in WSNs applications. Furthermore, the images shown in Figure 7 using the proposed technique are processed through the third decomposition level (quantization level=10) with minimum energy consumption.



(a) 9/7 DWT : PSNR=29.27dB

(b) The modified 9/7 DWT : PSNR=19.23 dB

Fig. 7. Comparison of image quality after 9/7 DWT and the proposed technique using the Photograph 256×256 grayscale image sample (Compression level = 3; Quantization level = 10).

However, in terms of system lifetime, the modified 9/7 DWT approach has better performance, as described in the next simulation results using the ns-2 simulator.

V.3. System lifetime

In this section, we compare the proposed technique with the 9/7 DWT in terms of system lifetime. We consider the model described in [7] with ten connected networks of size N=24, 50, 75, 100, 125, 150, 200, 225 and 250 nodes. The simulation is stopped if any node/cluster head in the network depletes its energy. In this study, we were interested by analyzing the response of the request between the source node and the base station. The system lifetime in terms of number of sessions is shown in Figure 8.

The results show that considerably longer system lifetime can be achieved when using the modified 9/7 DWT.

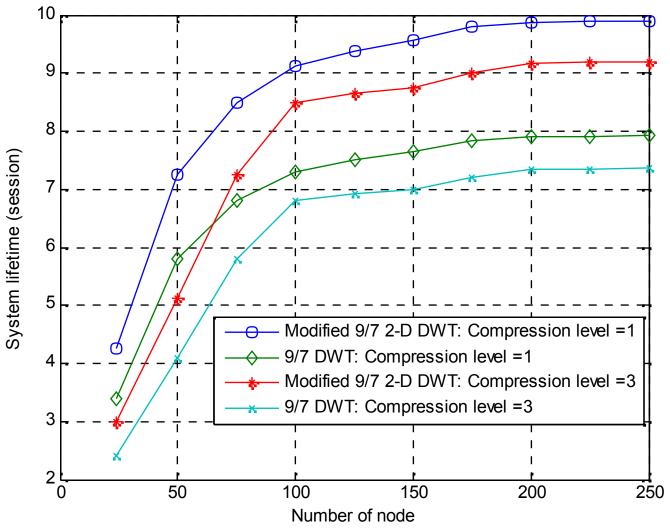


Fig.8. System lifetime comparison: Modified 9/7 2-D DWT versus 9/7 DWT

CONCLUSION

In this paper, we studied the problem of energy efficient image compression in multihop wireless sensor networks. We introduce an image compression scheme driven by energy efficiency considerations. The proposed scheme is simple and easy to implement in wireless sensor network applications. Performance evaluation shows that the proposed approach can have significantly computational energy while satisfying the performance constraint in terms of a target image quality compared to the standard approach.

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