Energy-aware JPEG for Visual Sensor networks

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Abstract

We address the problem of modeling and adapting JPEG to the energy requirement of Visual Sensor Networks (VSN). An Energy-aware adapted version of JPEG, called Squared JPEG (S-JPEG), is discussed. S-JPEG exploits the energy compaction property of the two-dimensional discrete cosine transform (2D DCT), to reduce both the redundant data within the sent image and the energy dissipated by a source node. S-JPEG addresses the VSN applications that face severe energy constraints and do not need a full image quality at the sink, such as video-surveillance. An energy model is developed for both JPEG and S-JPEG. Moreover, we used a simplified routing protocol to validate our theory. A set of simulations are conducted to show the performance of our work.

Key words: DCT, Image compression and transmission, JPEG, S-JPEG, Simulations, Visual Sensor Networks.

1 Introduction

Visual Sensor Network (VSN) is an ad-hoc wireless sensor network made of visual sensors (VS) incorporating image retrieving, processing and communication functionalities. VSN is gaining attention in a wide range of applications such as video-surveillance, object detection/tracking and environmental monitoring [7]. One of the biggest challenges facing VSN is a huge amount of visual information processed and sent by each VS. This information requires important resources in memory, processing and communication energy. Typically, visual information needs to be compressed using one of the well known compression standards such as JPEG or JPEG2000 to save energy and prolong the network lifetime. Unfortunately, these standards are energy consuming and generate compressed information that still contains highly correlated data, which might be compressed further.

We believe that the adaptation of these standards to the requirements of VSN is an attractive idea. This idea deserves to be studied in depth, to ensure an efficient compression in terms of energy minimization and system lifetime maximization, while maintaining an adequate image quality at the sink. In this work, we focus on the adaptation of JPEG to the requirements of VSN networks, even if JPEG 2000 performs better than JPEG. This adaptation is made in such a way to minimize the processing energy inside one VS, and maximize the system lifetime. In VSN, the energy constraint problem that faces JPEG can be alleviated by exploring the characteristics of the energy compaction property of the Discrete Cosine Transform (DCT) for highly correlated image. We exploit this property to reduce both the redundant data within an image and the energy dissipated by each VS. For transmission reasons, a simplified routing protocol is developed which considers only the energy of neighboring nodes when making next-hop routing decisions.

Image transmission over VSN has been the subject of many works, for example [3, 5]. The authors of [3] studied the energy consumption and the image quality in wireless video-surveillance networks, when retransmission of corrupted packets is performed. They used JPEG with integer DCT kernel as compression algorithm, instead of the commonly used floating point DCT to minimize delays and transmission costs. The authors do not really adapt JPEG to the energy requirement of VSN. The authors in [5] showed only the feasibility of transmission of JPEG images over ZigBee nodes, without further details. The exploitation of the 2D DCT energy compaction property was previously used in [11] and [1]. The authors in [11] investigated this idea in centralized wireless multimedia networks which differ from VSN requirements. This property was also used in [1] to design an energy-aware VLSI system for portable devices to compress an image.

The rest of this paper is organized as follows. The network model and the radio transceiver energy model are presented in section 2. In Section 3, we introduce S-JPEG. In Sections 4 and 5, we present the model of energy consumption of JPEG and S-JPEG, respectively. We introduce the routing module, in Section 6. In Section 7, we validate our results by a set of simulations. We summarize and present future directions in Section 8.
2 System model

A clustered two-tiered VSN is considered. The network is divided into several clusters, where each cluster contains some VS nodes and a single cluster head (CH) distributed around strategic areas. Each VS from the network is assumed to consist of a low-power imaging sensor such as Cyclops [8] connected to an embedded sensor such as Mica2 motes. Each VS is responsible for image retrieving, processing and transmitting from areas of interest to its CH. Two assumptions are used in our network model. The first one is that the VS nodes are suitably distributed in a strategic area to ensure that the network is fully connected. Each node communicates with its neighbors within its transmission range d. All nodes are immobile and energy constrained. The second assumption is that each VS node knows its location through a localization algorithm as in [2], and keeps information about its neighbors such as ID number and the battery remaining energy.

The power consumption model for the radio is similar to the one proposed in [6]. The energy dissipated by a given VS for sending a single bit is $e_{Tx} = e_c + e_a d^\alpha$, and the consumed energy in reception per bit is $e_{Rx} = e_c$. Where $e_a$ is the energy consumed by the transmit amplifier per bit over a distance of 1 meter, $e_c$ is the energy dissipated by the transmitter electronics per bit, $2 \leq \alpha \leq 4$ is the path loss exponent and $d$ is the distance between the sender and the receiver [9]. Therefore, the total energy consumed for transmitting a bit between two nodes is $e_b = e_{Tx} + e_{Rx}$. In our work, we consider the linear multihop scenario as in [6]. For n hops between the source and the sink, the multihop energy per bit is:

$$e_b = n e_{Tx} + (n - 1) e_{Rx} \quad (1)$$

3 Principle of S-JPEG

Herein, we present the DCT energy compaction property exploited by Squared JPEG (S-JPEG), which is defined by the fact that the signal energy is unevenly distributed in the DCT domain. The DC coefficient and some low to middle frequencies AC coefficients monopolize most of the signal energy. Thus, many AC coefficients in the range of high-frequencies can be discarded without much loss of information. This property is exploited to reduce the number of basic operations needed at each stage of the compression scheme, and hence minimizing the energy dissipated by each node. We use the notion of Reduced Block Size (RBS), which consists in processing only the upper-left squared portion (whose side’s length is $\rho$) of each block of $k \times k$ DCT coefficients of a given image (i.e., low frequencies), see Figure 2. The other coefficients are not considered, and hence not computed, which minimizes the energy dissipated by the source node.

4 Energy model of JPEG

A new energy consumption model for JPEG compression chain is developed. The energy dissipated in compressing the image at the source node is expressed in a number of operations needed at all stages of the compression scheme of Figure 1. Let $E_p$ be the required energy to process the image data for JPEG stages. $E_p$ can be formulated as follows:

$$E_p = E_{dct} + E_q + E_z + E_{rle} \quad (2)$$

Where $E_{dct}$, $E_q$, $E_z$ and $E_{rle}$ represent the energies consumed at 2D DCT, quantizing, zigzagging and RLE stages, respectively. The energy consumed for image splitting is neglected for simplification reasons, whereas the energy of entropy encoding will be considered in our future work.
4.3 Zigzagging energy model

4.3.1 2D DCT Energy model

We develop an energy consumption model for 2D DCT transformation based on the 2D DCT equation given by: [12]

\[ F(u, v) = \frac{C(u)C(v)}{\sqrt{2k}} \sum_{x=0}^{k-1} \sum_{y=0}^{k-1} \cos \left( \frac{2x+1}{2} u \pi \right) \cos \left( \frac{2y+1}{2} v \pi \right) \] (3)

Where \( u, v \) are the discrete frequency variables such that \( 0 \leq u, v \leq k-1 \), \( k \) is the block size; \( f(x, y) \) is the grey level of one pixel at \((x, y)\) in the \( N \times N\) image, where \( 0 \leq x, y \leq k-1 \); \( F(u, v) \) is the coefficient of the point \((u, v)\). The coefficients \( C(u) \) and \( C(v) \) are equal to \( \frac{\sqrt{2}}{2} \) if \((u, v) = 0\), and to 1 if \( 1 \leq u, v \leq k-1 \). Based on Eq. 3, the 2D DCT can be modeled as two \( k \times k \) matrix multiplications:

\[ F(k \times k) = A(k \times k) P(k \times k) A^T(k \times k) \] (4)

Where the index \((k \times k)\) indicates a size of matrix, \( F \) is the \( k \times k \) matrix whose coefficients are \( F(u, v) \), \( P \) is the matrix of pixels of the original image and \( A^T \) is the transpose of \( A \) whose coefficients are:

\[ A(u, v) = \begin{cases} \frac{1}{\sqrt{k}} & \text{if } (u = 0) \\ \frac{1}{\sqrt{2k}} \cos \left( \frac{u+1}{2} v \pi \right) & \text{if } (1 < u < k-1) \end{cases} \] (5)

Each matrix product \( k \times k \) of Eq. 4 consists in computing \( k^2 \) coefficients, each coefficient necessitating \( k \) multiplications and \( (k-1) \) additions\(^1\). Therefore, the energy dissipated for the two matrix products is \( 2k^2(ke_{\text{mult}} + (k-1)e_{\text{add}}) \), where \( e_{\text{mult}} \) and \( e_{\text{add}} \) represent the energy consumption for \texttt{mult} and \texttt{add} instructions, respectively. The Equations 6-11 of this section will be presented in forms which will make easy the comparisons of energy consumption of JPEG with that of S-JPEG. For an image of size \( N \times N \) having \( \left( \frac{N}{k} \right)^2 \) blocks, the total energy dissipated in this stage is:

\[ E_{\text{det}} = \left( \frac{N}{k} \right)^2 e_{\text{det}} = \left( \frac{N}{k} \right)^2 2k^2(ke_{\text{mult}} + (k-1)e_{\text{add}}) \] (6)

4.2 Quantization energy model

The energy consumption by the quantization stage can be expressed as a function of \( F(u, v) \) and \( Q(u, v) \), where \( F(u, v) \) is defined by Eq. 3 and \( Q(u, v) \) is a coefficient of the luminance quantization matrix \( Q \) defined as in [12] for \( k = 8 \). For each block, quantization consists in computing

\[ F^Q(u, v) = \text{IntegerRound} \left( \frac{F(u, v)}{Q(u, v)} \right), \text{ for } 0 \leq u, v \leq k-1 \]

Therefore, there are \( k^2 \) divisions and \( k^2 \) round operations per block and the energy dissipated is \( e_q = k^2(e_{\text{div}} + e_r) \), where \( e_{\text{div}} \) and \( e_r \) are the energy consumed for \texttt{div} and \texttt{round} instructions, respectively. For one image \( N \times N \), the total energy dissipated in this stage is:

\[ E_q = \left( \frac{N}{k} \right)^2 e_q = \left( \frac{N}{k} \right)^2 k^2(e_{\text{div}} + e_r) \] (7)

4.3 Zigzagging energy model

This stage can be interpreted as a simple rearrangement of the \((k^2-1)\) AC coefficients ordered in a zigzagging way, from lower to higher frequencies. Each AC coefficient is then moved (shifted) to its new position. The zigzagging energy consumption on each block can be calculated as:

\[ e_z = (k-2) e_{\text{sh}}, \text{ where } e_{\text{sh}} \text{ represents the energy consumption of the shift process. For one input image of size } N \times N, \text{ the total energy consumption related to the zigzagging stage is:} \]

\[ E_z = \left( \frac{N}{k} \right)^2 e_z = \left( \frac{N}{k} \right)^2 (k-1) e_{\text{sh}} \] (8)

4.4 RLE energy model

Run length encoding of the \((k^2-1)\) AC coefficients can be interpreted mainly as a rearrangement of the zigzagged sequence as follows, where \( 0 \text{seq} \) denotes a sequence of zeros:

1. If the zigzagged sequence terminates by a \( 0 \text{seq} \), the latter is replaced by \((0,0)\), meaning End Of Block (EOB). For the other \( 0 \text{seqs} \), we proceed as explained in the following points 2-4.

2. Each \( 0 \text{seq} \) of length \( L \) is decomposed into \((L \text{ div } 16) 0 \text{seqs} \) of length 16 and a last \( 0 \text{seq} \) of length \((L \text{ mod } 16)\). Note that after this decomposition, each \( 0 \text{seq} \) of length \( < 16 \) is followed by a non-zero coefficient.

3. Each \( 0 \text{seq} \) of length 16 is replaced by \((15,0)\), meaning that a zero is preceded by 15 zeros.

4. Each \( 0 \text{seq} \) of length \( r < 16 \) and the non-zero value \( X \) that follows are replaced by \((r,X)\), meaning that \( X \) is preceded by \( r \) zeros.

To compute the energy dissipated by one block, we consider the following parameters. \( e_z \) is the consumed energy for checking whether an AC coefficient is null. \( e_{\text{wr}} \) is the dissipated energy for writing one \((r,X)\) value (see above Points 3-4). \( e_{\text{inc}} \) is the dissipated energy for incrementing

\(^1\)Our goal is to implement our energy model, and do not develop a new fast DCT algorithm.
The counter of the number of $0$ in each $0seq$. $e_{res}$ is the consumed energy for resetting the counter. $N_{0seq}$ is the number of $0seqs$ inside one $k \times k$ block. Let us denote these $0seqs$ by $0seq[1]$, $0seq[2]$, $\cdots$, $0seq[N_{0seq}]$, and let length($i$) be the number of zeros in $0seq[i]$. Therefore, the total number of zeros inside one block is $N_0 = \sum_{i=1}^{N_{0seq}} \text{length}(i)$.

The total energy can be estimated as follows. The values of $(k^2 - 1)$ AC coefficients are checked, dissipating the energy $(k^2 - 1)e_z$, and $((k^2 - 1) - (N_0 + N_{0seq}))$ is the number of non-zero AC coefficients which are not preceded by $0seq$. Each coefficient $X$ of this category necessitates to write $(0, X)$, dissipating in total the energy $((k^2 - 1) - (N_0 + N_{0seq}))e_{wr}$. For each non-zero value and the $0seq[i]$ that precedes it, we consider $p_i = \text{length}(i) \mod 16$ and $q_i = \text{length}(i) \mod 16$. After decomposition, we obtain $(p_i + 1)0seq$. Each of these $0seq$ necessitates to reset the counter and to write $(r, X)$, dissipating in total the energy $(p_i + 1)(e_{res} + e_{wr})$. Each of the first $p_i \times 0seq$ (whose length is $16$) necessitates to increment the counter 15 times, and the last $0seq$ (whose length is $q_i$) necessitates to increment the counter $q_i - 1$ times, dissipating in total the energy $(15p_i + q_i - 1)e_{incr}$. The energy $e_{0seq}(i)$ is then:

$$e_{0seq}(i) = \begin{cases} (p_i + 1)(e_{wr} + e_{res}) + (15p_i + q_i - 1)e_{incr}, & \text{if } i < N_{0seq} \lor (\text{Last component } \neq 0) \\ e_{wr}, & \text{else} \end{cases}$$

The total energy dissipated inside one block of $k \times k$ is:

$$e_{rtc} = (k^2 - 1)e_z + (k^2 - 1) - (N_0 + N_{0seq})e_{wr} + \sum_{i=1}^{N_{0seq}} e_{0seq}(i)$$

For one image having $N \times N$ dimensions, the total energy dissipated by RLE stage is:

$$E_{rtc} = \sum_{j=1}^{N^2} e_{rtc,j}$$

where $e_{rtc,j}$ is the energy consumed by the $j$th block computed using Eq. 10. The energy consumption model of S-JPEG is considered in the next Section.

**5 Energy consumption of S-JPEG**

The energy consumption model of S-JPEG is based on the energy model of JPEG developed in Section 4. We have seen that with JPEG, for each $k \times k$ DCT block, $k^2$ coefficients are processed and transmitted. The gain in energy using S-JPEG, is basically due to the fact that $\rho^2 (< k^2)$ coefficients are processed and transmitted. It is therefore clear that the energy $E_p^0$ dissipated by S-JPEG is lower than $E_p$ dissipated by JPEG. Let us compute the energy consumed for each stage of the compression scheme as we have done with JPEG, and quantify the gain resulting for the passage from JPEG to S-JPEG. $E^0_p$ is defined as follows:

$$E^0_p = E^0_{dct} + E^0_q + E^0_z + E^0_{rtc}$$

(12)

Where $E^0_{dct}$, $E^0_q$, $E^0_z$ and $E^0_{rtc}$ are the energies consumed at 2D DCT, quantizing, zigzagging and RLE stages, respectively. Let us develop the energy model of S-JPEG, being inspired from the model of all stages of JPEG. In the DCT stage, if we consider the matrix product of Eq. 4, we are then interested only by the upper-left squared portion of size $\rho$ of $F(kxk)$. For this reason, it is sufficient to consider only the matrix product of Eq. 13, where the expression $U_{(a,b)}$ means the upper-left squared ($a$ lines; $b$ rows) portion of a matrix $U(kxk)$.

$$F_{(\rho x \rho)} = A_{(\rho x k)}P_{(kxk)}A^T_{(kx \rho)}$$

(13)

The first product $A_{(\rho x k)}P_{(kxk)}$ consists in computing $k^2\rho$ coefficients. Each coefficient necessitating $k$ multiplications and $(k - 1)$ additions. Let $R_{(\rho x k)}$ be the result of this first product. For the second product $R_{(\rho x k)}A^T_{(kx \rho)}$, we need to compute only $\rho^2$ coefficients, each of them necessitating $k^2$ multiplications and $(k - 1)$ additions. Therefore, the total energy dissipated per block is: $e_{dct} = (k^2 - \rho^2)(k\rhomult + (k - 1)e_{add})$ where $\rhomult$ and $e_{add}$ represent the energy consumption of mult and add instructions, respectively. The Equations 14-19 of this section will be presented in forms which will make easy the comparisons of energy consumption of JPEG with that of S-JPEG.

For a given image of size $N \times N$, the 2D DCT energy consumption $E^0_{dct}$ is therfore:

$$E^0_{dct} = \left(\frac{N}{k}\right)^2(k^2 + \rho^2)(k\rho\rho_{mult} + (k - 1)e_{add})$$

(14)

From Eqs. 6 and 14, the gain in energy for the DCT stage is $\frac{E^0_d}{E^0_{dct}} = \frac{\phi^2(k^2 + \rho^2)}{\phi^2(k^2 + \rho^2)} < 1$, where $\phi = \frac{k}{\rho}$.

For the following stages (quantization, zigzagging, RLE), we consider $\rho^2$ coefficients instead of all $k^2$ coefficients of a DCT block, and hence, only $\rho^2$ operations. We obtain Eqs. 15-19.

In Quantization stage, the energy $E_q$ (Eq. 7) obtained with JPEG becomes $E_q^0$ (Eq. 15) with S-JPEG:

$$E^0_q = \left(\frac{N}{k}\right)^2\rho^2(e_{div} + e_r)$$

(15)

From Eqs. 7 and 15, the gain in energy for the quantization stage is $\frac{E^0_q}{E_q} = \phi^2$, where $\phi = \frac{k}{\rho}$.

In Zigzagging stage, the energy $E_z$ (Eq. 8) obtained with JPEG becomes $E_z^0$ (Eq. 16) with S-JPEG:

$$E^0_z = \left(\frac{N}{k}\right)^2(\rho^2 - 1)e_{sh}$$

(16)

The gain in energy for zigzagging stage is computed from Eqs. 8 and 16 and is $\frac{E^0_z}{E_z} = \frac{\phi^2 - 1}{\phi^2 - 1}$.
In RLE stage, the energy $e_{rle}$ (Eq. 10) obtained with JPEG becomes $e^e_{rle}$ (Eq. 17) with S-JPEG.

$$e^e_{rle} = (\rho^2 -1) e_z + ((\rho^2 -1) - (N_0^{\rho} + N_{seq}) e_{w_r} + \sum_{i=1}^{N_{seq}} e_{seq}(i))$$ \hspace{1cm} (17)

Where, $N_0^{\rho}$ is the number of 0seqs inside the reduced block of size $\rho \times \rho$, $N_0$ is the number of zeros inside the reduced block of size $\rho \times \rho$, and

$$e_{seq}(i) = \begin{cases} (p_i + 1)(e_{w_r} + e_{rle}) + (15p_i + q_i - 1)e_{inc}, & \text{if } (i < N_0^{\rho}) \lor (Last \_component \neq 0) \\ e_{w_r}, & \text{else} \end{cases}$$ \hspace{1cm} (18)

Since $\rho^2 < k^2$, $N_0^{\rho} < N_0$ and $N_0^{\rho} < N_{seq}$ we obtain $e^e_{rle} < e_{rle}$. If we consider one image of dimension $N \times N$, the energy $E_{rle}$ (Eq. 11) obtained with JPEG becomes $E^e_{rle}$ (Eq. 19) with S-JPEG, where $e^e_{rle}$ is the energy consumed by the $j$th block computed using Eq. 17.

$$E^e_{rle} = \sum_{j=1}^{(N/\rho)^2} e^e_{rle}$$ \hspace{1cm} (19)

From Eqs. 14-19, we deduce that $E^e_p < E_p$.

6 Routing module

We used a simple routing scenario summarized as follows. First, after receiving the image query $I_q$, the source node $S$ takes an image $I$, and compresses it by JPEG or S-JPEG. After that, $S$ sends their packets to its cluster head $CH_1$. Then, based on the energy of neighboring nodes, $CH_1$ selects from its neighboring table, the set of nodes $S_{nf}$ (in its cluster) that are able to forward the received packets. If $S_{nf}$ is empty, i.e., there is no “eligible” nodes, $CH_1$ forwards the received packets directly to the $CH$ of the next cluster, thus consuming more energy (Figure 3). After that, each node $n_j$ from $S_{nf}$ sends the received packets to a node $n_{next}$ belonging to the neighbor cluster. In its turn, $n_{next}$ forwards the received packets to its cluster head $CH_2$. If there is no node of the neighbor cluster inside the range of transmission of $n_j$, the packets will be sent directly to $CH_2$ (cluster head of the neighboring cluster), thus consuming more energy. This process will continue until the reception of all packets by the base station.

7 Simulations

We perform several simulations using Matlab. We study the effects of varying $\rho$ on both the consumed energy by a source node and the quality of the received image at the sink. After that, we compare JPEG with S-JPEG in a simple routing scenario (Figure 3) according to the following performance metrics. 1) The Cluster lifetime which means that the cluster is in life if there is at least one active sensor inside the cluster. The cluster lifetime is closely related to $\rho$. If $\rho$ is high, the source node consumes more energy, which reduces the cluster lifetime, and vice versa. 2) The Energy consumption during communication and processing tasks. 3) The Image quality measured by the peak signal-to-noise ratio (PSNR) expressed, in decibels, as follows, where $a$ is number of bits per pixel (bpp), $f$ and $f'$ are the original and the reconstructed images.

$$PSNR = -10 \log_{10} \frac{1}{N^2} \sum_{x=1}^{N} \sum_{y=1}^{N} |f(x,y) - f'(x,y)|^2 \frac{1}{(2a - 1)^2}$$

We consider a scenario in which a clustered VSN is deployed around strategic locations. The visual sensor network, formed by 300 nodes (e.g. Mica2 motes), is placed in a square region of size $50 \times 50$ m$^2$. We suppose that the number of sensors per cluster varies between 6 and 20 nodes, and each node has an initial energy of 10 Joules. A node is considered non-functional if its energy level $E_l$ reaches 0, and cannot take an image if $E_l < E_p$ for JPEG, or $E_l < E_p$ for S-JPEG. The node communication range $d$ is fixed at 10 m. The values of the parameters $e_a$, $e_c$ and $\alpha$ of the radio transceiver model are $e_a = 100 \times 10^{-12}$ Joule/bit/m$^2$, $e_c = 50 \times 10^{-9}$ Joule/bit and $\alpha = 2.5$ as in [10].

To evaluate the energy consumed by JPEG (Eq. 2) and S-JPEG (Eq. 12), we adopted the parameters of Mica2 motes as in [4], for example, $e_{add} = 3.3$ Joule. For space limitation, we do not present the numerical computations. The reader is invited to consult the references cited in this section.

7.1 Effects of $\rho$

In this simulation, we show the two effects (Energy-effect/Quality-effect) of varying $\rho$ on the source node energy and the image quality. The energy-effect means that the energy consumed by one source node for processing an image increases with $\rho$. This is explained by the fact that the number of AC coefficients processed increases with $\rho$, which necessitates more processing energy (See Figure 4 for Lena image having $512 \times 512$ pixels and 8 bpp).
7.2 Effect of $\rho$ on the performance metrics

In this section, we simulate the effect of varying $\rho$ on the following performance metrics, while maintaining an adequate image quality at the sink; 1) the energy dissipated through the path between the source and the sink computed using (Eq. 1 and Eq. 2) for JPEG, and (Eq. 1 and Eq. 12) for S-JPEG, and 2) the cluster lifetime. That is, in S-JPEG we replace $\rho$ by different values between 1 and 8, and analyze the effect of this replacement on these performance metrics. We use the notation $S$-JPEG($\rho$) to mean that S-JPEG is used for a given value $\rho$, for example $S$-JPEG(5) means that S-JPEG is used for $\rho = 5$. We suppose that the distance between the source and the sink takes several hops, from 1 to 30. In our simulations, we focus on a unicast traffic pattern (Figure 3).

We consider the same example of Lena image, and we compute the energy dissipated through the path used during a whole cycle\(^2\) to send this image using S-JPEG for each value of $\rho = 1$ to 8. We consider different numbers of hops between the source and the destination. For a given number of hops, we use the same path for all values of $\rho$, in order to evaluate clearly the influence of $\rho$. Our results are represented in Figure 6 which shows that the total energy dissipated by JPEG in the whole path is high compared to the energy dissipated with S-JPEG for each $\rho$ equal to 2, 4, and 6, which confirms that S-JPEG consumes less energy compared to JPEG, especially when $\rho$ is relatively small.

To show the effect of $\rho$ on the cluster lifetime, we consider the following scenario. The same node from one clus-

\^2\)The cycle starts by image capturing and ends at the reception of the image by the sink.
The problem of compressing, using JPEG, while transmitting images over VSN is considered. An Energy-aware adapted version of JPEG, called S-JPEG, was discussed. To adapt JPEG to the requirements of multihop VSN, we investigated the concept of Reduced Block Size (RBS), which consists in processing only the upper-left squared portion (whose side’s length is \( \rho \)) of each block of \( k \times k \) DCT coefficients of a given image. Moreover, we presented a new energy model for JPEG and S-JPEG. We used a simplified routing protocol to validate our theory. Our simulations show how S-JPEG improves JPEG energetically, while maintaining an adequate image quality at the sink. We would like to emphasize that the proposed method is useful and easy to implement. One direction for our future work is to implement it on a VSN testbed. We also plan to study the effects of the reduced block size concept on other performance metrics like the processing time, the bandwidth and the network state.

8 Conclusion

The problem of compressing, using JPEG, while transmitting images over VSN is considered. An Energy-aware adapted version of JPEG, called S-JPEG, was discussed. To adapt JPEG to the requirements of multihop VSN, we investigated the concept of Reduced Block Size (RBS), which consists in processing only the upper-left squared portion (whose side’s length is \( \rho \)) of each block of \( k \times k \) DCT coefficients of a given image. Moreover, we presented a new energy model for JPEG and S-JPEG. We used a simplified routing protocol to validate our theory. Our simulations show how S-JPEG improves JPEG energetically, while maintaining an adequate image quality at the sink. We would like to emphasize that the proposed method is useful and easy to implement. One direction for our future work is to implement it on a VSN testbed. We also plan to study the effects of the reduced block size concept on other performance metrics like the processing time, the bandwidth and the network state.

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