

Wavelet Transform Based Effective Energy Utilisation Approaches of Data Transfer in Wireless Sensor Networks: A Survey

UMAR FAROOQ, JYOTI SAXENA, SHABIR AHMAD SOFI

Abstract-- In recent years, wireless sensor networks (WSNs) featured an exponential growth, which has revolutionised the field of telecommunication. A wireless sensor network consists of a group of tiny battery powered sensor nodes capable of reading, processing and reporting the data to the Base station (sink). One of the major issues faced by sensor nodes is the energy constraint due to the limited energy sources in the form of tiny batteries. Therefore energy efficient data transfer presents the major challenge in a WSN. In this paper we investigate various Wavelet Transform based Effective Energy Utilisation approaches of data transfer in WSNs. These approaches can be used significantly to minimise the energy necessary for the efficient data communication in WSNs while meeting the constraints of data quality and bandwidth of wireless sensor networks.

Keywords-- Wireless Sensor Networks (WSNs); Discrete Wavelet Transform (DWT); PSNR; Discrete Cosine Transform; Image Compression; Skipped High-pass Sub-band (SHPS).

I. Introduction

A wireless sensor network (WSN) is a wireless network consisting of spatially distributed small battery powered sensor nodes to cooperatively monitor physical or environmental conditions. Originally the sensor networks were motivated by military applications, However the use of WSNs

have now grown in many civil applications like environmental monitoring, health applications and traffic control [5] [7] [8]. In WSNs, as depicted in Fig.1, data is collected by various sensor nodes and transmitted to a special node called Base station or sink. These nodes are energised by very small and irreplaceable batteries hence providing an energy constraint condition. Under these energy constraint conditions, it is useful to transmit only a limited amount of data bits by compressing the data using the different compression techniques like Discrete Cosine Transform, Wavelet Transform in order to reduce the energy consumption[1][13][17][18][19].

Under this context, image (2-D signal) transmission over WSN is done mainly after using the compression algorithm based on Wavelet transform in order to reduce number of bits used to represent the image by eliminating the various redundancies, thereby reducing the energy consumption in image transfer. Adaptive compression based congestion control technique [14] is one of the approaches utilising the wavelet transform to reduce the number of packets so as to provide efficient energy consumption mechanism. In work [12] open loop and closed loop image transmission schemes based on Discrete Wavelet transform (DWT) were proposed which provide graceful trade-off between image quality and energy utilisation to transmit the image data. Skipped High-pass Sub-band (SHPS) technique [15] [16] is one of the effective approaches of image transmission utilising DWT. A distributed algorithm based on lifting scheme [9] so as to decorrelate the collected data at nodes by the exchange of data among other sensor nodes in network path is also an efficient approach of reducing overall energy consumption using the right trade off among local processing and transmission operations.

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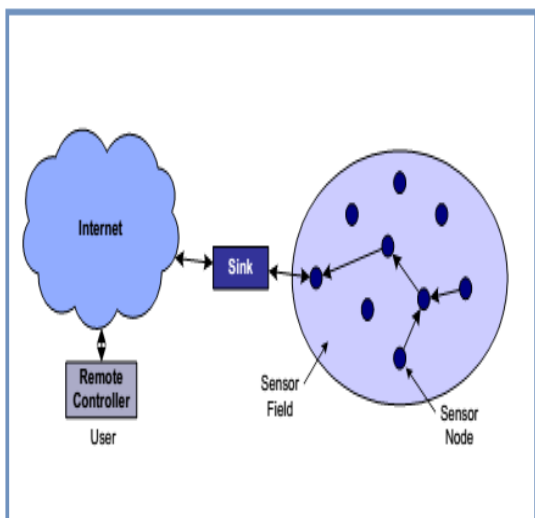


Fig.1. Sensor Network Architecture

II. Related work

For reduction of data collision, P Huang et al. [20] discussed effective media access control protocols. Chen et al. [10] focussed on investigating QoS of WSNs for meeting high bandwidth demands. Routing protocols for WSNs were reviewed intensively by J.N. Al-Karaki and A. E. Kamal [11]. However all these papers focussed on different aspects while our work aim at wavelet transform based effective energy utilisation approaches of data transfer in Wireless Sensor Networks.

There has been a limited but appreciable amount of work done related to the data transfer in WSNs using Wavelet Transform (WT). Alexandre Ciancio and Antonio Ortega [9] developed a distributed algorithm based on lifting scheme so as to decorrelate the collected data at nodes by the exchange of information between neighbouring sensor nodes so as to reduce overall energy consumption using the right trade off among local processing and transmission operations. Vincent Lecuire et al. [12] aimed to develop energy efficient loop based schemes and investigated the impact of using DWT in these schemes. Mohsen Nasri et al. [15] [16] provided energy efficient algorithm called Skipped High-Pass Sub-band technique. Lee JH and Jung IB [14] focussed on efficient energy consumption using Wavelet Transform by packet reduction using Adaptive compression based congestion control technique (ACT).

III. Wavelet Transform based effective energy utilisation approaches in WSN

Discrete Wavelet Transform [2][4] involve the High and Low pass filters to be used for dividing the input image data into four non-overlapping multi-resolution sub-bands LL , LH , HL and HH on the first level. The sub-band LL gives the detail DWT coefficients while as the approximate coefficients are given by the sub-bands LH , HL , and HH . The LL sub-band contains the low pass information and the others contain the high pass information of the horizontal, vertical and diagonal orientation. DWT has been used as an important tool for energy efficient data transfer in WSNs. Various DWT based effective energy utilisation approaches in WSNs are a discussed below.

A. Distributed wavelet algorithm based on lifting scheme

In the distributed wavelet algorithm based on lifting scheme [9], at each of the sensors $5/3$ wavelet coefficients are generated. Odd numbered sensors would correspond to the odd samples and even numbered sensors to the even samples-*i.e.* the lifting scheme of wavelet [3] is performed in two stage distributed way, as illustrated in Fig. 2.

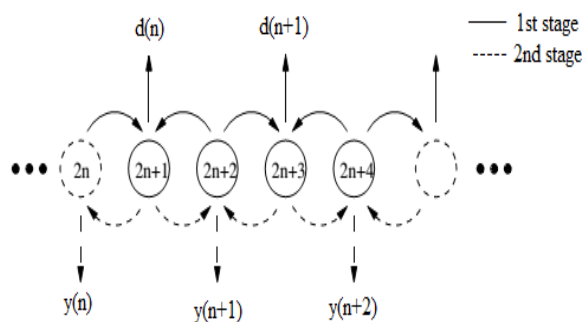


Fig. 2. Two stage Wavelet transform implementation using lifting scheme

During first stage, the odd-numbered sensors would receive the data from the even numbered neighbouring sensors and from this data detail coefficients from DWT are computed. In the second stage of process, these detail coefficients are then forwarded to even numbered sensors and then to central node. The even sensors use these detail coefficients along with their own

measurements so as to generate the smooth coefficients which are then transmitted to the central node.

It is fact that for non- distributed case, there is no energy consumption with inter-sensor transmission or local processing as the quantised measurements are directed simply to the central node. However in distributed wavelet algorithm, both local processing and inter sensor transmissions are introduced hoping that the obtained decorrelated data will require less energy for transmission to the central node.

For both transmission and processing energy consumed depends on processor used. For example the processor “strongARM SA-1100” [6], the energy consumption of k bit packet transmission and reception over distance D is as:

$$E_T = E_{el} + E_{amp} \times k \times D^2$$

$$E_R = E_{el} \times k$$

Where E_{el} is the energy consumed to run transmit and receive electronics and E_{amp} is the energy consumed by transmit power amplifier.

The energy consumed during computation is as:

$Elp = N \times C \times V_{dd}^2$, where N is number of clock cycles, V_{dd} is the supply voltage and C is the average capacitance switched per cycle.

For strongARM SA-1100[6]

$$E_{el} = 50nJ/b, E_{amp} = 100pJ/b/m^2, C = 0.67nF$$

Hence the total energy consumed at sensor is given as:

$$Es = Elp + Elt + Elr + Ert$$

where Elp , Elt , Elr , Ert represent energy consumed in local processing, local transmission, local reception and remote transmission respectively.

B. Loop schemes based on DWT

Open loop and closed loop schemes [12] based on DWT were proposed to provide a graceful trade-off between the power utilisation to transmit the image data and the quality of the reconstructed image. In both of these schemes, the image is first partitioned into ‘ p ’ resolution levels by applying the 2-D DWT ‘ $p-1$ ’ times. This helps in performing the data packet prioritisation *i.e.* the packets carrying the image header and the lowest image resolution (represented by the LL_{p-1} sub-band) are assigned priority level ‘0’, as they are most important. The subsequent image resolution levels from 1 to ‘ $p-1$ ’ are having the decreasing importance, so the packets carrying the l^{th} resolution (represented by HL_{p-l} , LH_{p-l} and HH_{p-l} sub-bands) are assigned

priority level l . So once the image is transformed by DWT and packetized into different priorities, the packets are ready to be sent.

In open loop based scheme, an intermediate node performs its decision independently without considering the available energy in other nodes. In this scheme, when a packet arrives at a node, two informations are required for the operation to proceed smoothly, one is the priority level of the packet and other is the total number of priority levels. This information is given in the source node by filling the packet header fields. A 4-byte long byte packet header is used in this case and is depicted in Fig. 3 containing image identification number, the data offset in the whole image, total priority levels (p) and the packet priority level (l)

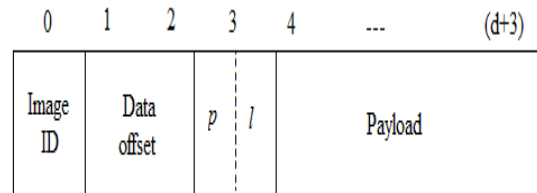


Fig. 3. Packet Format of data used by open loop scheme.

In order to make decision whether to discard or forward a received packet, intermediate node refers to the third and fourth fields of the packet header in addition to its thresholds. The destination node uses the first and second fields of the packet header to store the data before decoding. For missing data, zero is substituted by the destination node.

In closed loop scheme, the intermediate node performs its decision on basis of the energy available at other nodes in the network path *i.e.* a node can discard a packet even if it has got sufficient energy to forward them, if it knows that other node in its network path has not got sufficient energy. The intermediate node gets the information of other nodes from the received acknowledgement packets.

For 2-D Discrete Wavelet transform, an energy consumption model is given in [9] based on 5-tap/3-tap wavelet filter. The basic operations are performed as: 8-shift and 8-add instructions are required for low pass decomposition while 2 shift and 4 add instructions are required for high pass decomposition. If the image size is of $M \times N$ pixels and the DWT is applied iteratively T times, then the energy consumption during these processes is as:

$$E_{DWT}(M,N,T) = M \times N \times (10S + 12A + 2R_{mem} + 2W_{mem}) \times \sum_{i=1}^T 1/4^{i-1} \quad (1)$$

Where S , A , R_{mem} , W_{mem} are energy consumptions for shift, add, read and write of basic 1-byte instruction respectively.

To get reference, [12] evaluated the consumed energy by transmitting the image using open loop scheme without application of DWT, in this case energy consumed to transmit the original image is 846.39 mJ. However on applying 1-level DWT, the simulation results show that energy consumptions are 258.38 mJ and 218.26 mJ i.e there are energy savings of 69% and 74% respectively for open loop and closed loop approaches. Similarly on applying 2-level DWT the obtained results show that there are energy savings of 87% and 94% respectively for open loop and closed loop approaches. However image quality is not so good i.e. PSNR is only about 32.25dB in case of 2-level DWT, motivating to develop more efficient signal processing algorithm.

C. Skipped high pass sub band technique.

In order to save computational energy and achieve a graceful PSNR, an adaptive image transmission approach in WSNs consisting of a technique in which certain high pass coefficients of an image are skipped, thus conserving the energy by skipping the least significant sub band. This technique is referred as Skipped High-Pass Sub-band Technique [15] [16]. In this technique after applying DWT, high pass and low pass coefficients are obtained. The high pass coefficients are represented by small integer values, infact most of high pass coefficients are less than 0.2. As the image presents a low pass spectrum, so high pass filtering is skipped. Hence a lot of energy is saved with minimum image quality loss by not computing high pass coefficients.

In SHPS, attempts to conserve energy are made by skipping the least significant sub band Hi in each transform level. The low pass sub bands are further decomposed leading to LLi and LHi sub bands. By skipping two out of every four sub bands, SHPS technique reduces computational loads i.e. only LLi and LHi sub bands are computed.

On applying SHPS technique, during row transform computational load is same as equation 1. However in case of column transform high-pass sub-band(HH and HL) are not computed, resulting

in decrease of computational operations hence resulting in decrease of computational loads. The computational load savings are given as:

$$C_{sav} = 1/4 \times M \times N \times (8A + 8S) + 1/4 \times M \times N \times (4A + 2S) \quad \text{i.e. } C_{sav} = 1/4 \times M \times N \times (12A + 10S) \quad (2)$$

That means 25% savings compared to equation 1. Hence the computational load for SHPS technique is as:

$$C_{SHPS} = M \times N \times (30S + 36A) / 4 \times \sum_{i=1}^T 1/4^{i-1} + M \times N \times (12A + 10S) \times \sum_{i=T+1}^{p-1} 1/4^{i-1} \quad (3)$$

Since high-pass sub-band from the row transform are not computed in the column transform, we are able to save half of “read and write” operations i.e. 25% saving with respect to $1/2 \times M \times N \times (2R_{mem} + 2W_{mem})$. The data access load in SHPS technique is therefore as:

$$C_{READ-SHPS} = C_{WRITESHPS} = 3/2 \times M \times N \times (2R_{mem} + 2W_{mem}) \sum_{i=1}^T 1/4^{i-1} + M \times N \times (2R_{mem} + 2W_{mem}) \times \sum_{i=T+1}^{p-1} 1/4^{i-1} \quad (4)$$

It is observed in [15] [16] that SHPS technique can save up to 25% of energy for level 1 decomposition and 33% for level 3 decomposition. However there is considerable image quality loss associated with this technique: PSNR=26 dB for level 1 and 24 dB for level 3. Thus by applying SHPS technique, different trade-offs should be considered between energy consumption for image compression and transmission and the reconstructed image quality.

D. Adaptive compression based congestion control technique

In WSNs, the congestion results in an increased amount of data loss and also creates delays in data transmission. These problems cause the PSNR to degrade and hence the increased amount of energy consumption. In order to overcome this problem, a Wavelet transform based technique called Adaptive compression based congestion control technique (ACT) [14] was developed for packet reduction. The detail of this technique is illustrated in Fig. 4

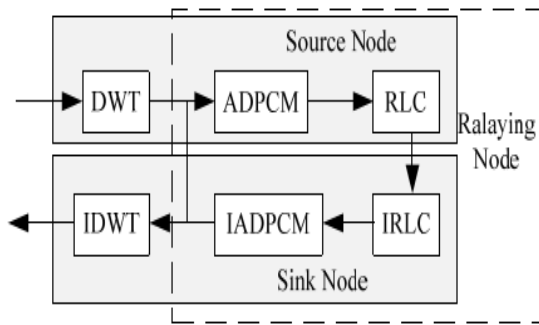


Fig.4. Adaptive Compression Scheme

The collected data or image is transformed by DWT, and then with help of ADPCM the range of data is reduced. Also the numbers of packets in this technique are reduced by Run Length Coding (RLC) before data transfer to sink node. The sink node applies inverse ADPCM and inverse DWT to reconstruct the original image

The above algorithm is fruitful in terms of saving the energy consumption but it is suitable only for small data set and images and demands development in its algorithm regarding energy utilisation savings in case of transfer of bulky images and larger data sets.

IV. Possibility and Challenge

Energy consumption operation of a wireless sensor node comprises of sensing, processing and transmission. Among these, data transmission is the most power consuming task (80% approx.). Thus if we are able to minimise size of data by compression based on DWT, it will reduce the transmission power. However if we apply the data

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compression algorithm, more power for processing may be required. Moreover on employing the compression algorithms the energy consumption for data transmission may be reduced but at the cost of degrading the recovered data quality because compression results in minimising the data used to represent the image[12][15][16].

In order to reduce the overall energy consumed the sum of energy consumed by transmitting and processing has to be reduced i.e. the sum of energy consumed by compressing 'm' bits into 'n' bits and transmitting these 'n' bits should be smaller than energy consumed by transmitting 'm' uncompressed bits, moreover maintaining the quality of recovered data.

V. Conclusion

In wireless sensor networks transmission of an image (2-D signal) requires huge amount of data to be transferred creating significant energy and bandwidth constraints that need to be addressed. This paper presents a diversity of Wavelet Transform based Effective Energy utilisation approaches in Wireless Sensor Networks. Active research regarding the reduction of redundant data with the help of DWT based techniques like Distributed wavelet Algorithm, SHPS technique, Adaptive compression based congestion control technique (ACT), Loop based schemes have different ways of dealing with energy utilisation of WSN however they have focussed on the same goal of achieving the prolonging residual energy of Sensor nodes with minimum degradation of recovered data quality.

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