Computer Science and Information Systems 17(2):509–536 https://doi.org/10.2298/CSIS191124008S

Fuzzy Logic and Image Compression Based Energy Efficient Application Layer Algorithm for Wireless Multimedia Sensor Networks

Arafat SENTURK[1], Resul KARA[1], and Ibrahim OZCELIK[2]

[1] Deparment of Computer Engineering, Engineering Faculty, Duzce University
Duzce, Turkey
{arafatsenturk,resulkara}@duzce.edu.tr
[2] Deparment of Computer Engineering,Faculty of Computer and Information Sciences,Sakarya University
Sakarya, Turkey
ozcelik@sakarya.edu.tr

Abstract. Wireless Sensor Networks (WSN) are the networks that can realize data processing and computation skills of sensor nodes over the wireless channel and they have several communication devices. Wireless Multimedia Sensor Networks (WMSN) are the networks composed of low-cost sensor nodes that transmit real-time multimedia data like voice, image, and video to each other and to sink. WMSN needs more energy and bandwidth than WSN since they transmit a larger amount of data. The size of the data transmitted by the sensor nodes to each other or the sink becomes an important factor in their energy consumption. Energy consumption is a fundamental issue for WMSN. Other issues that affect the progress of WMSN are limited bandwidth and memory constraints. In these networks, for which the node battery lives are important sources, the limited sources must be effectively used by decreasing the transmitted data amount by removing the redundant data after proper processing of the environmental data. A new algorithm is developed to minimize the energy consumption during image data transmission between sensor nodes on WMSN, and so, make the nodes use their most important source, battery life effectively in this study. This algorithm is named as Energy-aware Application Layer Algorithm based on Image Compression (EALAIC). This algorithm makes use of the top three image compression algorithms for WMSN and decides instantly to which one is the most efficient based on three parameters: the distance between the nodes, total node number, and data transmission frequency. In this way, the sensor node battery lives are used efficiently. The performance analysis of the developed algorithm is also done via Network Simulator – 2 (NS – 2) and it is compared by the existing algorithms in terms of energy rate (consumed energy/total energy) and PSNR (Peak Signal to Noise Ratio).

Keywords: Energy efficiency, Fuzzy logic, Image compression, Wireless multimedia sensor networks.

1. Introduction

Wireless Sensor Networks (WSN) become widespread easily because of some features such as being more appropriate to natural conditions than wired communication, being more reliable, having a flexible structure, producing solutions with low cost, self-organization, using the energy in a balanced way inside the network, and ease of installation. The purpose of WSN is to give access to data at any time and from everywhere easily. They do this function by collecting, processing, analyzing, and transmitting data [4], [28]. WSN has drawn the attention of the researchers since it can easily solve the practical and theoretical difficulties. Another reason for the increasing popularity is using small devices for transmitting data to far distances after some basic operations are done in physical environments. Besides, WSN has been used frequently in many military and unmilitary applications since it avails to measure some physical phenomena like temperature, pressure, moisture, and location [50].

Wireless Multimedia Sensor Networks (WMSN) are the networks that are composed of low cost sensor nodes that transmit real-time image, video or audio data to each other. Audio and visual data may exist together in a single device or they may exist separately. Besides, WMSN can store real-time multimedia data after retrieving from several sensor nodes [34]. WMSN leads to the most hopeful developments in real-time multimedia monitoring. But having a larger amount of data for transmission when compared with WSN makes the life and efficient energy usage important problems for WMSN [27]. In addition, energy efficiency has been studied extensively in sensor networks [44],[45],[9],[46],[16]. [31] focuses on the energy-aware image transmission in WMSN for flood images. In this paper, the researchers applied image segmentation and the useless parts of the images were removed before transmission. This approach may achieve good performance in flood images in which mostly the trees and sky are at the top of the image and the flood water are at the bottom and overlay a considerable part of the image. Middle part of the image, transition between the land and water, as accepted as the most important part of the image. For that kind of images segmentation can be applied and the regions out of ROI can be removed and then this downsized image can be transmitted. But for example Lena image that we used in our experiments consists of many details on the whole image and the proposed segmentation method does not work for this kind of cases. Energy consumption is the fundamental issue for WMSN. The sensor nodes in the network consume most of their energy during data retrieval and the performed operations. Therefore, proper design is required to maximize the lifetime of wireless sensor networks. Other issues that affect the development of WMSN are limited bandwidth and memory constraints [4],[29].

Delivery of multimedia data requires higher bandwidth than traditional sensor networks and this situation affects the design of WMSN [15]. Designing low complexity encoders and decoders besides high compression ability is an important application layer problem in WMSN for which energy preservation is rather necessary [15]. Some algorithms can be developed to process raw data retrieved from the environment and only the important data can be transmitted instead of unnecessary data. Thus, the size of transmitted data can be reduced and energy consumption can be minimized [33]. Reliability, congestion control, latency minimization, and error check are the requirements provided in the transmission layer in terms of quality of service. Quality of service-based routing and forwarding schemas are the research topics of the network layer. MAC layer protocols should contain priority-based and latency aware timing algorithms [15],[55]. This layer controls the biggest part of radio communication, and so, it plays an important role in energy efficiency and reducing latency [22].

1.1. Image compression algorithms used for WMSN

There are many types of research related to energy efficiency in WMSN and these researches can be classified according to the layer they correspond to. In the application layer, especially the improvements in image compression algorithms constitute an essential part of the researches. The image compression algorithms used for WMSN are given in the following part.

Low Energy Image Compression Algorithm (LEICA) developed by Sun *et al.* [41] claims to minimize energy consumption by shrinking the data amount without any deformation in image quality. LEICA first divides the image into two layers as background and foreground. This layered structure is named as ROI (Region of Interest). The important content falls into the foreground and the relatively important image is in background. The unimportant background image is compressed more than the important foreground image. In this way, both image qualities are preserved and the compression ratio is increased, and so, the energy efficiency is provided.

The first image compression algorithm used in WMSN is Embedded Zero Tree Wavelet (EZW) [39] is modified by Said *et al.* to make encoding and decoding faster and it is named as SPIHT (Set Partitioning In Hierarchical Trees) [35]. SPIHT converts the pixel data of the image in a tree structure and collects the most related pixels in a single set. Then, zero-valued trees are encoded in a single value. Combining this feature of wavelet transform and SPIHT achieves a high compression ratio in images.

Thanks to the algorithm developed in [2], JPEG2000 formatted images are considered to be transmitted in a low-energy fashion without any deformation in image quality. Unnecessary bits inside the image are removed in this study for less-energy data transmission. But it is understood that the sensor nodes in WMSN are not suitable for JPEG2000 formatted image compression in terms of hardware and it consumes more energy than expected. Mulugeta *et al.* have proposed a secure forwarding protocol for sensor networks in [30]. Minimizing the energy consumption in image compression, processing and transmission are aimed at this study.

Discrete Wavelet Transform (DCT) is an image compression technique that is frequently used in WMSN. DCT based image compression techniques provide proper compression efficiency. Since encoding is done after the image is decomposed into small data blocks, it can also be used in low-memory applications [3].

The network was divided into two layers in [43] as camera nodes and common nodes which fulfil the compression duty. Images were divided into blocks and the largest-energy nodes were selected, and then wavelet transform was applied seperately. Several nodes do the compression of a subpart of the image at the same time and parts are then combined in order to maintain load balancing in the network. Besides, unlike LEACH they considered the residual energies of the nodes and the average energy consumption for cluster head selection.

Image was transmitted by three methods in [17]. Transform coding, conventional compressed sensing and a new compressed sensing method used together. In the new compressed sensing method they used inverse binary DCT method. It is shown that the proposed approach is more enrgy efficient than DCT based other approaches.

In [47], the authors developed and object detection based energy efficient transmission method. They first determines the object presence and sends image segments instead of sending whole image. The reciving node constructs the whole image based on the frames it took earlier. Their purpose is to use the approach in real time object tracking. They did not give the details of the experiments like the distance between the nodes, size of the area, number of hops for a transmission, *etc.*

Compression of video data was handled in [20]. Repeated features between the frames and redundant features were eliminated to reduce bit rate of the video stream. Authors evalute the frames in terms of their inter ayer features and remove redundant features. They do not evaluate each frame seperately. Therefore, this approach can not be used for the compression of images as in our case.

1.2. Energy-aware protocols for layered architecture

In the following part of the study, energy-aware protocols which are proposed for WMSN are explained based on a layered architecture. Energy-aware studies are given starting from the physical layer to application layer.

New technology with less latency and higher data rate are needed for multimedia communication. Even IEEE 802.15.4 provides high data efficiency in radio inactive status, its energy consumption is rather more. In [40], energy-saving IEEE 802.15.4 is handled. The method adjusts activeness according to traffic conditions in radioactive status and provides energy saving with less latency. In [24], a method based on radio interval and frame process adjustment with RED (Random Early Detection) queue management is proposed. The method aims to improve the performance of WMSN by reducing end to end latency and packet losses.

MAC protocols work for satisfying the quality of service requirements in the application layer. MAC layer has a differing important when compared with other layers because of its responsibilities like reducing collusion and number of retransmissions, minimizing energy consumption and interferences, and maximizing reliability and consistency [15]. In [37], a CSMA-CA (Carrier Sense Multiple Access with Collision Avoidance) based MAC protocol is proposed. Traffic classes are given priority according to the jumped node numbers. Also, to reduce collision possibility it allows interfering to report messages. In [6], both TDMA (Time Division Multiple Access) and contention based CSMA used together for scheduling different traffic flows concerning priority. Service difference is ensured by the queue management schema. High-priority traffic has more chances to access the medium and the latency is reduced. Some MAC protocols include additional processes that require sniffing also in a sleep state to make high-priority data has a greater chance [18], [12].

The fundamental difficulties in routing protocols are to optimize network performance and provide energy preservation while satisfying the quality of service requirements [15]. Quality of service metrics in the routing layer is end to end delay, packet loss, the total number of hops, bandwidth, connection quality, and energy. A geographic routing protocol has been proposed in [36]. End to end delay is ensured by evaluating the position relative to the base stations, remaining energy and queue length in the next node. In [7], a routing approach that maximizes network lifetime by balancing energy consumption in the nodes is presented. Service differentiation is used to access the base stations in the acceptable delay interval. In the other study, the cluster heads use ant colony optimization to find the optimal path through base station [8]. In [51], different service requirements are considered for different traffic flows. These are some service constraints like delay, packet loss, remaining energy in the nodes, and required number of hops for every path.

The method works in the way that the base station broadcasts a query indicating its needs and all subjacent nodes check their sources and added to the path if they have more resources than required. In [21], energy efficiency in WMSN was considered in terms of finding optimum routing paths and managing network load with respect to energy reserves of the nodes. Their routing protocol aves the overall energy by preventing useless data transmission using an energy threshold. Similarly, [25] also deals with finding optimal paths in a WMSN for QoS and balanced energy distribution. They do not consider to reduce packet size for multimedia transmission in WMSN. [1] focuses on the efficient transmission of video over WSN. It proposes a routing protocol and transmits packets based on their priority through the scored paths. There are aso many efforts in recent literatüre for energy aware routing [19], AODV routing protocol was enhanced in [11] considering not only the number of hops in a transmission, but also the residual energies and the congestion issues for an energy efficient routing.

The transport layer plays an important role in the communication over sensor networks with delay constraints. Congestion detection and reduction, end to end delay, and reliability requirements must be satisfied besides energy constraints [15]. Different traffic flows occur in WMSN and each flow may have its own reliability, error and delay constraints. All these constraints must be satisfied for every traffic flow separately. Transport layer protocols in traditional WSN are not suitable for WMSN. No service differentiation, flexible delay intervals, the importance of reliability of the event, not the application are the features that distinguish WMSN from WSN [15].

Pixel-based Wyner-Ziv encoder is proposed as a proper application layer operation [4], [14]. However, this encoder causes delays since it requires many feedbacks from the decoder part. In [56], pixel based Wyner-Ziv the encoder is applied in a sliced structure with automated rate selection. Sending only necessary parity bits and so efficient usage of bandwidth is purposed. Encoder takes the data quality in the end side and sends an appropriate number of parity bits for a successful encoding. In a different study, a two-phase protocol has been proposed [48]. In the first phase, compression gain which is obtained when interrelated cameras encode together is measured by an entropy based discreteness metric. Then, an optimal clustering hierarchy is established for encoding. Therefore, the global compression gain is maximized besides the reliability in the decoder part. Maximization of compression is achieved by ensuring the selection of the clusters with minimum entropy, and reliability is achieved by ensuring all camera nodes are covered at least in two of selected clusters.

Insufficiency of studies in the application layer and the idea to develop more energy-efficient approaches by combining realized improvements with the improvements in other layers have to lead develop an energy-aware method to work in the application layer. Thus, the network lifetime will be prolonged by minimizing the amount of data to be transmitted and selecting the most suitable compression algorithm according to the network condition (distance between nodes, the total number of nodes and data transmission frequency).

The main contributions of the proposed energy aware approach are as follows:

- Instant determination of image compression algorithm among the most efficient compression mthods used in WMSN based on the network condition,
- Acceptable PSNR value is checked to satisfy QoS requirements of WMSN,
- Compression ratio is not fixed, i.e. it can be increased if acceptable PSNR is preserved,

- Fuzzy rule based approach is used during the determination of compression algorithm,
- Comprehensive experiments are conducted to investigate the consumed energy and residual energy of the network based on several parameters which are distance between the nodes, data transmission frequency, and number of nodes. Also, PSNR values are calculated for different compression ratios.
- A comprehensive overview of the literature is realized and the obtained results are compared by the state-of-the-art to show the performance of the proposed method.

In the first part of the paper, WSN and WMSN are mentioned briefly. The image compression algorithms used for WMSN are mentioned and energy aware studies related to WMSN are given based on layered architecture. In the second part, the image compression algorithm to be used in the developed algorithm is decided through the referenced research. Next, operation principles of EALAIC are given. In the third part, the performance criterions of WMSN are considered and the parameters of the simulation are mentioned. Afterward, a performance evaluation of EALAIC is done based on energy rate, end to end delay and total energy consumption via the comparison with the other referenced works. The results are given in the fourth part and future works are proposed.

2. Energy - Aware Application Layer Algorithm Based on Image Compression

Image compression methods in WMSN are divided into two groups as lossy and lossless methods. Lossy methods provide important advantages since they have less encoding/decoding time, better compression ratio, and usability in energy-limited applications. Image size in lossless compressed images is considerably greater than the lossy one, and so, the sensor nodes need more power and bandwidth when transmitting images. Therefore, lossless image compression methods are not preferred in WMSN [53]. Three image compression algorithms that give the best solutions in terms of energy efficiency in WMSN stand out in [38]. These algorithms are DCT, SPIHT, and LEICA.

In this part of the paper, the energy-aware method, EALAIC which is based on DCT, SPIHT, and LEICA to be used for WMSN is given. The parameters of EALAIC and how they are obtained are specified below.

A. Obtaining data about the distance between nodes: The sensor nodes in EALAIC have data about the distance between each other via a routing protocol, Modify-Adhoc On Demand Distance Vector Routing (M-AODV) which is obtained by changing "hello" packet in Adhoc On Demand Distance Vector Routing (AODV) routing protocol.

B. Determination of Number of Nodes and Data Transmission Frequency: The number of required nodes and data transmission frequency is determined in the network establishment phase. The reasons why the distance between nodes, number of nodes, and data transmission frequency are given in Section 2.1.

C. Determination of Compression Algorithm via Fuzzy Logic Method: EALAIC first processes the determined parameters for the selection and decides the algorithms to be used. Then, all parameters are considered among the determined algorithms and the most efficient one is decided. The detailed information is given in the following part of the section.

D. Determination of PSNR Value Loss and Its Conservation: PSNR value of the compressed image is calculated and the predetermined value loss interval is tried to be conserved. Therefore, both higher compression is obtained and the quality of the system is preserved. Required operations and sample analyses are in the following.

The data obtained by the above steps are processed by the decision tree method and converted into rule-based data. The selection of the most efficient image compression algorithm is done according to the data obtained by the fuzzy logic method. These operations are explained in detail in Section 2.1.

Reducing the transmission and acquisition energies spent by sensor nodes is aimed. Since the transmission and acquisition energies will be reduced, sensor nodes use their battery lives efficiently and the network lifetime is intended to be prolonged. Also, the PSNR value of the compressed image is kept in the acceptable interval for wireless communication and the image quality is aimed to be preserved.

The most efficient image compression is decided thanks to EALAIC and the energy spent by sensor nodes will be minimized. In the energy calculation operations, both the energy consumed by compression algorithms and the energy needed by EALAIC are considered. The structure of EALAIC is given in Figure 1.

Pseudo code of EALAIC is the following:

```
ALGORITHM EALAIC (cp, D, Ds)
//input : cp, respose to hello packet, the image size
//output: compressed image
//cp_x, cp_y, neighbour node coordinates
//S: data transmission frequency, Ds: number of nodes in network
node = node who sends hello packet
cp_x = take X coordinate inside respose packet
cp_y = take Y coordinate inside respose packet
node_x = take GPS_X coordinate
node _y = take GPS_Y coordinate
distance = sqrt((node_x-cp_x)^2+(node_y-cp_y)^2)
i = take_image
P = psnr(i)  //PSNR value of image i
D = 5     //Compression ratio
Sa = algorithmSelection(S,Ds,distance)
      //selection of compression algorithm
While do
Sg = COMPRESSimage(D,Sa,i)  // %D compressed image according to Sa
Sg_P = psnr(Sg)        //PSNR value of compressed image
if (P-Sg_P )< 25 ve (P-Sg_P) > 20
return i         //send data to node with cp_x,cp_y coordinate
else if (P-Sg_p) >= 25
D = D + 5
else D = D - 5
```

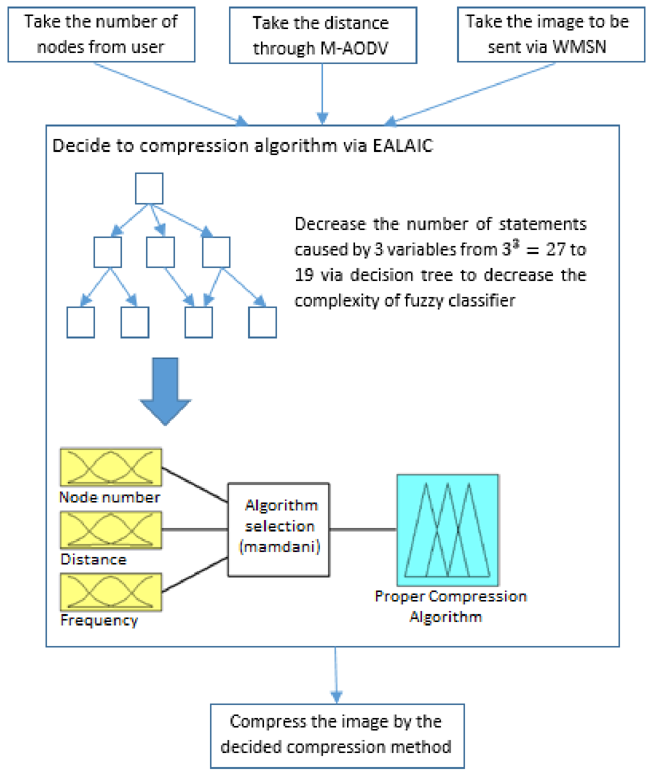

Fig. 1. Structure of EALAIC

2.1. Determination of Compression Algorithm via Fuzzy Logic Method

EALAIC has used a fuzzy logic method to determine the most efficient image compression algorithm. First, the numbers of states are minimized by the decision tree method and the most suitable method is decided by fuzzy logic method.

The parameters of EALAIC are specified based on the system needs. These parameters and the reasons why they are determined are:

- **A.** Distance between the sensor nodes in the network affects their transmission/acquisition energies [32]. This situation is taken into consideration and "distance between nodes" is determined as a parameter. The sensor nodes in the system may be mobile. Thus, the distance between nodes may change at any time. The linguistic variable of membership function is determined as "low" for the cases when the sensor nodes whose coverage area is 200 meters are close to each other, as "high" for the cases the distance is in the border, and "medium" for the cases the distance is neither "low" nor "high".
- **B.** The Number of sensor nodes over the network affects the total energy consumption. Energy waste is inevitable when there exist a greater number of nodes [26], [13]. Besides, the number of nodes also affects the coverage area of the application. Re-

quired node number can be determined by considering the coverage area of the sensor nodes [13]. “Number of nodes” is determined as a parameter trough these inferences. The coverage area of the system is stated by the user in the network establishment phase to obtain the number of nodes to be used for the network. The linguistic variables of fuzzy membership function formed by this calculated value are determined as “low”, “medium”, and “high”.

– **C.** Sensor nodes transmit the received image to the next sensor node in the coverage area after they perform some operations on the image. Transmission of this image data in a certain time interval is important in terms of energy. Because all nodes used in every transmission spend transmission/acquisition energy [52]. For this reason, “data transmission frequency” is used as a parameter in the system and the linguistic variables of fuzzy membership function are specified as “low”, “medium”, and “high” according to the user request.

Sensor nodes are made to select and use the most efficient algorithm thanks to EALAIC which is developed with the mentioned parameters. Energy consumption during compression (operation complexity), compression amount, quality loss in the output data, and the distance-based evaluation are effective in the selection of the most suitable compression algorithm. For example, in the distance based evaluation, a summation of the operation complexity and the energy consumed to transmit compressed image is calculated for every compression method and the one with less energy consumption is preferred. The method may have high the compression ability, but its operation complexity may also be high. Consuming a high amount of energy may be unnecessary when the distance to transmit data is short. Transmitting data after a simpler method with less operational complexity can be less costly. Therefore, the preferred compression method changes depending on the distance. The method with less complexity is preferred not to cause latencies in case of the evaluation based on transmission frequency and to minimize these latencies. In case when the number of nodes is variable, for instance when the number of nodes is high, number of hops will be high and every hop will bring additional cost. On top of it, if the operation complexity is also high, then the total cost will increase and so more energy will be consumed. This means operation complexity is effective in the evaluation based on the number of nodes.

There are three fuzzy input variables for the Fuzzy Logic Method. These are the ones determined for EALAIC and they are “number of nodes”, “frequency”, and “distance”. The fuzzy output variable is named as “the algorithm to be used”. The fuzzification operation whose block schema is given in Figure 2 is established by MATLAB 2014a Fuzzy Logic Toolbox.

Determination of the algorithm to be used according to the distance between nodes: “hello” packet in AODV routing protocol has been changed to calculate the distance between sensor nodes which are in the coverage area of each other and this protocol is named as Modified Adhoc On Demand Distance Vector Routing (M-AODV). The location information obtained via the GPS module on sensor nodes is added to the modified “hello” packet. This packet is delivered to the neighbors and they are informed about their locations. Then, the distance between nodes is calculated using this information. If M-AODV is not used, then geographic algorithms must be used. Geography based algorithms use many control packets and they consume a lot of energy [10], [23].

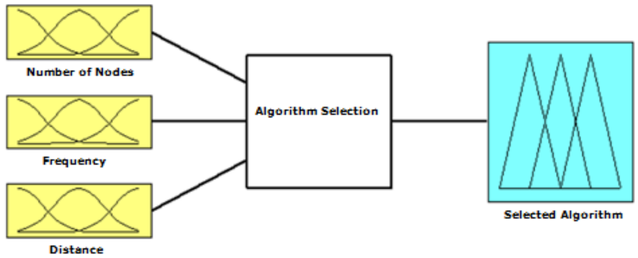

Fig. 2. Block view of fuzzy logic input and output variables

The frame structure of AODV "hello" packet is given in Figure 3 and its modified version is in Figure 4. The distance between nodes is calculated using the equality given in equation 1 thanks to the information provided by GPS module by taking location information of both nodes.

Type 1 Byte	Length 1 Byte	*"hello"* Message 4 Bytes

Fig. 3. Frame structure of "hello" packet

Type 1 Byte	Length 1 Byte	*"hello"* Message 4 Bytes	Location (x, y) 8 Bytes

Fig. 4. Frame structure of modified "hello" packet

$$M_{i,j} = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \quad (1)$$

The compression algorithm changes with respect to the distance between nodes. According to the simulation results, "energy rate (remaining energy/total energy)" versus distance between nodes is given in Figure 5 graphically for three compression algorithms.

It is shown by the graphics that DCT is the most efficient algorithm to be used for WMSN in terms of energy when the distance between nodes is low. When the distance between nodes is medium, using LEICA for image compression seems logical and if the distance between nodes is high, SPIHT is the most energy-efficient compression algorithm. However, sometimes the algorithm to be used for compression cannot be decided clearly. That is to say, the energy efficiency of more than one algorithm seems to be high for some distance intervals. When fuzzy logic is used to determine the best one for

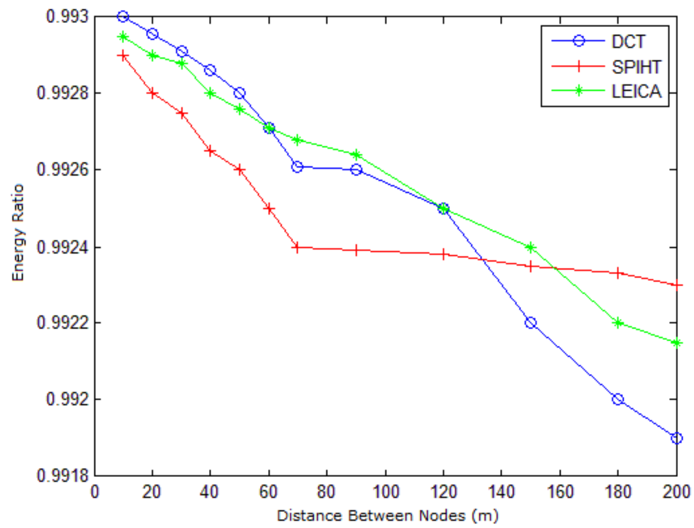

Fig. 5. Energy rate versus distance between nodes

these situations: "Distance" parameter changes between 0 and 200. Three membership functions have been constituted for this input variable and these are named as "low", "medium", and "high". The upper and lower limits of input variable "distance" are given in Table 1 and its graphical representation is in Figure 6.

Table 1. Membership function limits of input variable "Distance"

Linguistic variable	Membership function limit	
Low	0	70
Medium	50	120
High	100	200

As a result of this inference, DCT or LEICA will be used for compression in case "distance" parameter is "low and medium" and LEICA or SPIHT will be used when "distance" parameter is "medium and high".

Determination of the algorithm to be used according to the number of nodes: The required number of nodes according to the area where they will be set up is known on the average for any system since the area where the WMSN addresses are definite during establishment. The compression algorithm changes according to the number of nodes used for the network while the compressed image data is transmitted. According to the simulation results, "energy ratio (remaining energy/total energy)" versus the number of nodes in the network is given in Figure 7 graphically for three compression algorithms.

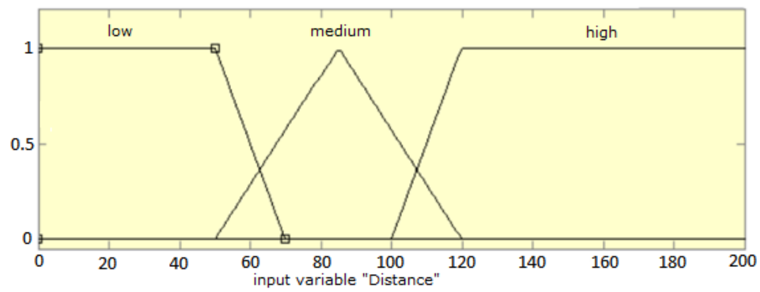

Fig. 6. Graphical representation of membership functions of input variable “Distance”

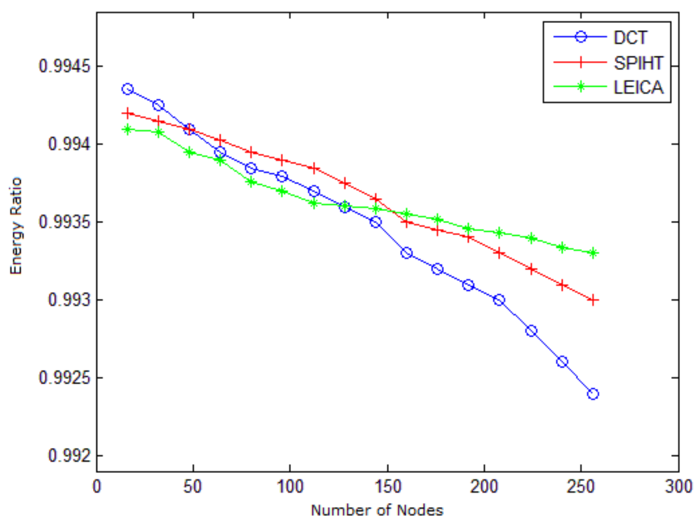

Fig. 7. Energy rate versus distance between nodes

It is shown by the graphics that DCT has the best energy rate when the number of nodes in the network is the lowest. LEICA algorithm seems to have the worst energy rate. However, DCT losses its efficiency as the number of nodes increase and SPIHT seem to be better. LEICA algorithm is at the forefront in the networks with high number of nodes. That is, using DCT is efficient in case the number of nodes in the lowest, using SPIHT is efficient when the number of nodes is medium and using LEICA is logical for the cases in which node number is the highest. As shown in Figure 7, the proper compression algorithm is not decided clearly for node numbers. Fuzzy logic is used for that kind of situation. "Number of nodes" parameter changes between 0 and 256. Three membership functions have been constituted for this input variable and these are named as "low", "medium", and "high". The upper and lower limits of input variable "Number of nodes" are given in Table 2 and its graphical representation is in Figure 8.

Table 2. Membership function limits of input variable "Distance"

Linguistic variable	Membership function limit	
Low	0	64
Medium	50	158
High	144	256

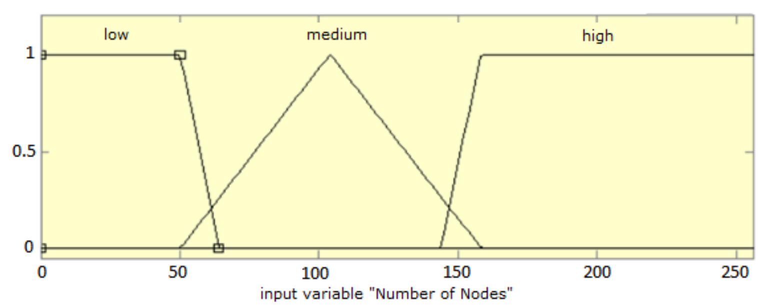

Fig. 8. Graphical representation of membership functions of input variable "Number of Nodes"

As a result of this inference, DCT or SPIHT will be used for compression in case the "number of nodes" parameter is "low and medium" and SPIHT or LEICA will be used when "number of nodes" is "medium and high".

Determination of the algorithm to be used according to data transmission frequency over the network: Data transmission-acquisition between nodes is realized at certain time intervals. This interval shows the data density in the network and it can be determined optionally during system establishment. The data transmission frequency of the sensors in the network changes between 2 seconds and 19 seconds. According to the simulation results, data transmission frequency versus "energy rate (remaining energy/total energy)" is given in Figure 9 graphically for three compression algorithms.

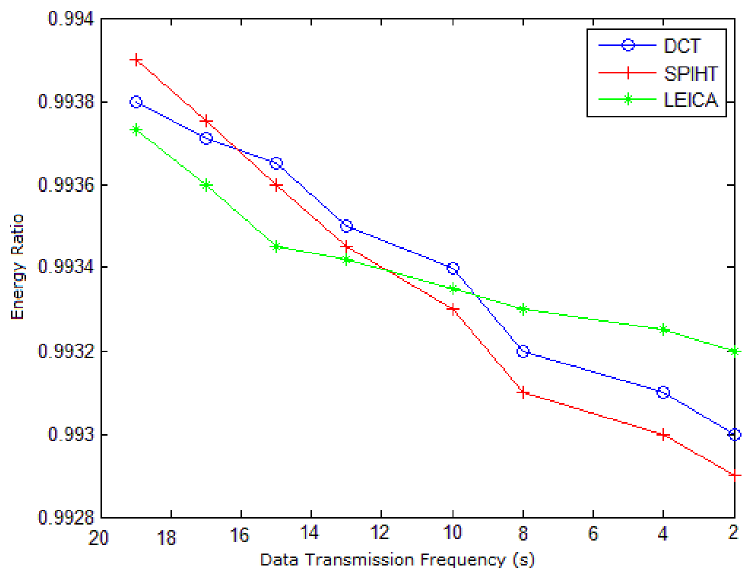

Fig. 9. Energy rate versus distance between nodes

It is shown by the graphics that SPIHT is the most efficient algorithm when the network is in peak time, i.e. data frequency is the highest. DCT algorithm seems to be better when the data frequency becomes lower and LEICA is the most efficient one when the frequency is quite low. However, like the other parameters, in some frequency intervals, there are overlaps and the fuzzy logic method is used to get rid of this problem.

Table 3. Membership function limits of input variable "Frequency"

Linguistic variable	**Membership function limit**	
Low	12	20
Medium	5	14
High	0	7

"Frequency" parameter changes between 0 and 19. Three membership functions have been constituted for this input variable and these are named as "low", "medium", and "high". The upper and lower limits of the input variable "Frequency" are given in Table 3 and its graphical representation is in Figure 10. As a result of this inference, SPIHT or DCT will be used for compression in case the "frequency" parameter is "high and medium" and DCT or LEICA will be used when "frequency" is "medium and low".

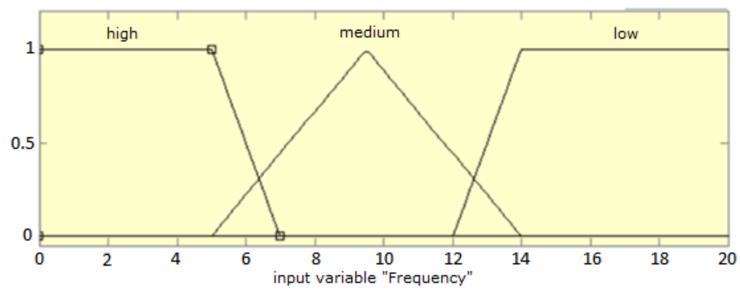

Fig. 10. Graphical representation of membership functions of input variable "Frequency"

Selection of image compression algorithm: "Selected Algorithm" value is obtained using above three input variables. For this purpose, three membership functions are constituted for "Selected Algorithm" output variable. Names of the algorithms (DCT, SPIHT and LEICA) to be used after the method works are given as linguistic variables of membership functions. The upper and lower limits of output variable "Selected Algorithm" are given in Table 4 and its graphical representation is in Figure 11.

Table 4. Membership function limits of input variable "Selected Algorithm"

Linguistic variable	Membership function limit	
Low	0	1
Medium	1	2
High	2	3

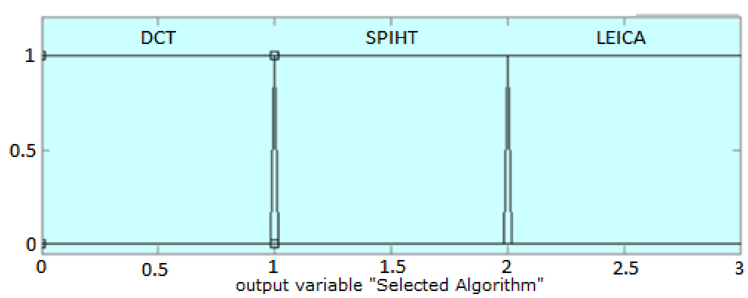

Fig. 11. Graphical representation of membership functions of output variable "Selected Algorithm"

2.2. Determination of PSNR value loss and its Conservation

PSNR value of the compressed image is calculated in the developed system. The acceptable PSNR loss value for wireless communication is about 20-25 dB [42]. If the difference between the original image and the compressed image is in the acceptable loss interval, then the image is transmitted to the next node or the sink. If the difference between the original image and the compressed image is less than or equal to 20 dB, then the compression ratio is increased and the image is transmitted to the next node or the sink after compressing the original image with higher compression ratio. However, if the difference between the original image and the compressed image is more than 20 dB, then the compression ratio is decreased and the image is compressed at lower ratio and sent. Conservation of the quality of the system will be provided by keeping PSNR value of the compressed image in the acceptable interval.

Sample images given below are used for the simulations in Section 3 and the inferences done in this section related to PSNR value loss.

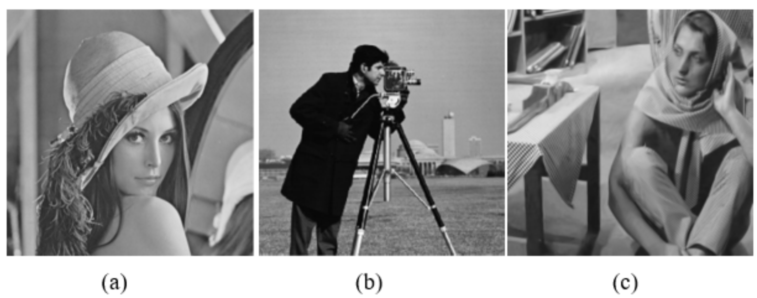

Fig. 12. (a) sample image 1, (b) sample image 2 ve (c) sample image 3

PSNR value loss versus compression ratio graphic of "sample image 1" data for every algorithm is given in Figure 13.

Table 5. Compression ratios with respect to PSNR values of sample images

	CR	PSNR	CR	PSNR	CR	PSNR	CR	PSNR	CR	PSNR
Image 1 (a)	0	98	5	85	10	81	15	77	20	74
Image 2 (b)	0	95	5	78	10	72	15	70	20	67
Image 3 (c)	0	93	5	87	10	74	15	72	20	69

It is shown in Figure 13 that the acceptable PSNR loss value can be reached by applying at most 20% compression ratio for "sample image 1" data. That is, PSNR value of the image decreases from 98 to 74 after compression. So, the PSNR value loss is 24 dB. When the compression ratio is increased to 25, then PSNR value loss will be 28 dB and this is out of the acceptable loss interval. Therefore, 20% compression ratio with 24 dB loss is the most suitable compression ratio.

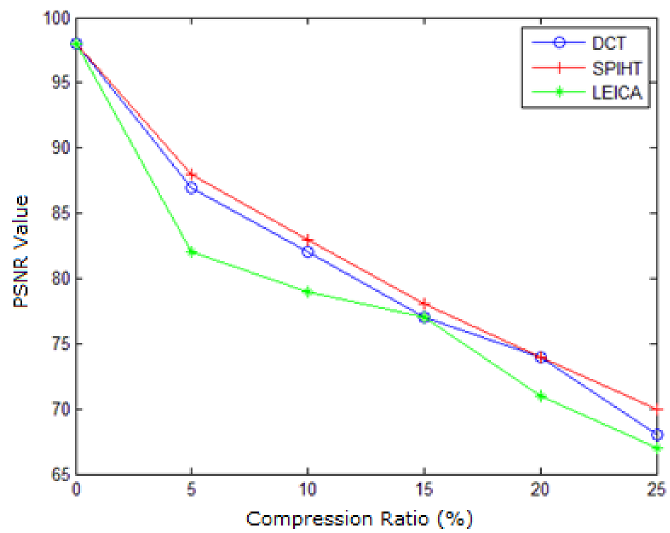

Fig. 13. PSNR value loss versus compression ratio graphic of "sample image 1" for three algorithms

Compression ratios (CR) of three sample image data with respect to their PSNR values are given in Table 5. EALAIC decides the compression ratio to be based on these values.

3. Performance Evaluation of EALAIC

3.1. Performance Criteria for WMSN

WMSN has some constraints like memory, processor, energy consumption, and lifetime. Memory and processor constraints can be overcome by the advances in technology. Enhancing energy consumption and so prolonging network lifetime become possible via the studies carried out [49]. The most important performance criterion for WMSN is energy consumption. More energy and bandwidth is needed to transmit multimedia data [4], [53]. The performance of the method proposed in this study is evaluated based on the following criteria:

- **Energy Consumption:** Energy consumption is evaluated in terms of three variables in the simulations and these are: distance between nodes, number of nodes, and data transmission frequency. Remaining energy after the data is transmitted is proportional to the performance of image compression algorithm used.
- **PSNR Loss Value:** PSNR value of the compressed image is measured in the simulations and image transmission is realized only when the PSNR value of the image decreases 20-25 dB. This interval is the acceptable loss measure for WMSN [42]. Also, the amount of data to be transmitted will be decreased by increasing the compression rate until the acceptable PSNR loss is satisfied. Therefore, the sensor nodes will consume less transmission and acquisition energy.

Calculation of the energy rate is realized under the consideration of the transmission/acquisition energies of the carrier nodes while they carry compressed data towards the sink. That is, a node inside the network takes the image, decides the proper image compression algorithm thanks to EALAIC, and the decided compression algorithm is applied to the image. Then, it sends the image to the next node according to the routing protocol. The neighbor node who takes the compressed data works only as a carrier and forwards the data to the next node. The carrier nodes spend only transmission and acquisition energies meantime. They do not spend computation energy.

Images used for the analysis are given in Section 2.2. Different sample scenarios are made for the performance evaluation and the sensor nodes are made the received images send to the next node under the below conditions. The conditions are:

- Without compression,
- Using only DCT,
- Using only SPIHT,
- Using only LEICA, and
- Using EALAIC.

3.2. Simulation Parameters

Scenarios and simulations are first realized for stationary networks. Then, the simulations are carried out for the networks with mobile nodes whose speeds are 5 m/s and 10 m/s. The nodes are placed by the grid model for stationary network simulation. As for mobile networks, the sensor nodes are first placed according to the grid model and then they are moved randomly. The simulation parameters are given in Table 6 and the images are given in Figure 12.

Table 6. Simulation parameters

Number of nodes	17, 101, 197
Packet size	256 Kbyte
Distance between nodes (meter)	10 - 200
Data transmission frequency (second)	3, 9, 15
Simulation time (second)	120

3.3. Energy Rate

1000-joule energy is assigned to every node as starting energy. The total energy is determined before the simulations according to the number of nodes in the network. The remaining energy is calculated after the simulation time ends. The rate of the remaining energy to the total energy is expressed as “energy rate”. Energy rate is a performance criterion that determines the energy efficiency of the simulation realized. Energy efficiency is determined as good for the cases in which the energy rate is high.

Figure 14 and Figure 15 show the graphics of a stationary network. EALAIC catches the best energy rate by using SPIHT with 10% compression ratio when data transmission frequency is 15 seconds, by using DCT with 5% compression ratio when data transmission frequency is 9 seconds, and by using LEICA with 20% compression ratio when data transmission frequency is 3 seconds in Figure 14. The corresponding energy rates are given in Table 7.

EALAIC catches the best energy rate by using LEICA with 5% compression ratio when the number of nodes is 17, by using SPIHT with 15% compression ratio when the number of nodes is 101, and by using SPIHT with 10% compression ratio when the number of nodes is 197 in Figure 15. The corresponding energy rates are given in Table 8.

Table 7. Scenario: energy rates of five methods with respect to data transmission frequency in the case that "Distance"-low and "Number of Nodes"-medium

Data Transmission	Energy Rate				
Frequency (sec)	**DCT**	**SPIHT**	**LEICA**	**EALAIC**	**Without Compression**
15	0.9918469	0.9919395	0.9919179	0.9921035	0.9887133
9	0.9912076	0.9911705	0.9910011	0.9912076	0.9819545
3	0.9891125	0.989661	0.9897173	0.9901256	0.9727593

Table 8. Scenario: energy rates of five methods with respect to number of nodes in the case that "Distance"-medium and "Data Transmission Frequency"-low

Number of	Energy Rate				
Nodes	**DCT**	**SPIHT**	**LEICA**	**EALAIC**	**Without Compression**
17	0.9938447	0.9939762	0.9944439	0.9944439	0.9928777
101	0.9930386	0.9930810	0.9930327	0.9932125	0.9900944
197	0.9925863	0.9926916	0.9923728	0.9927954	0.9889077

Figure 16 and Figure 17 show the graphics of a mobile network (nodes are moving with speeds 5 m/s and 10 m/s). EALAIC catches the best energy rate by using LEICA with 10% compression ratio when data transmission frequency is 15 seconds, by using SPIHT with 5% compression ratio when data transmission frequency is 9 seconds, and by using LEICA with 10% compression ratio when data transmission frequency is 3 seconds in Figure 16. The corresponding energy rates are given in Table 9.

EALAIC catches the best energy rate by using DCT with 10% compression ratio when the distance between nodes is 40 meters, by using DCT with 15% compression ratio when the distance between nodes is 90 meters, and by using LEICA with 5% compression ratio when the distance between nodes is 190 meters in Figure 17. The corresponding energy rates are given in Table 10.

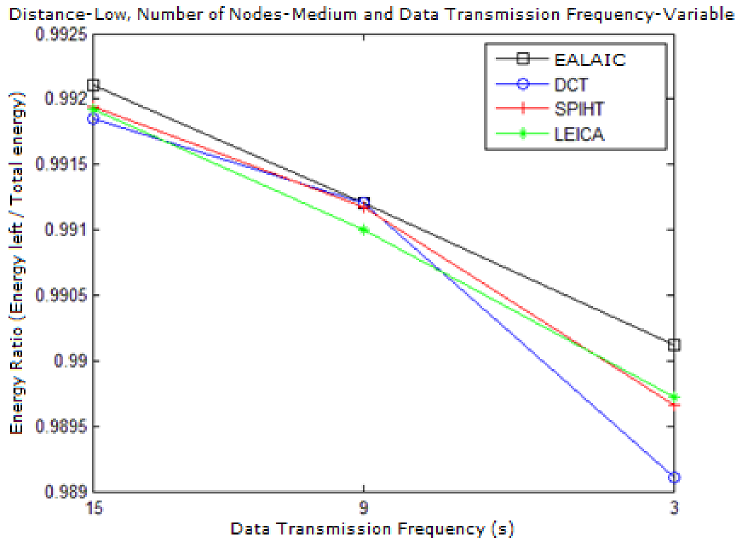

Fig. 14. Scenario: data transmission frequency versus energy rate graphic of four methods in the case that “Distance”-low and “Number of Nodes”-medium

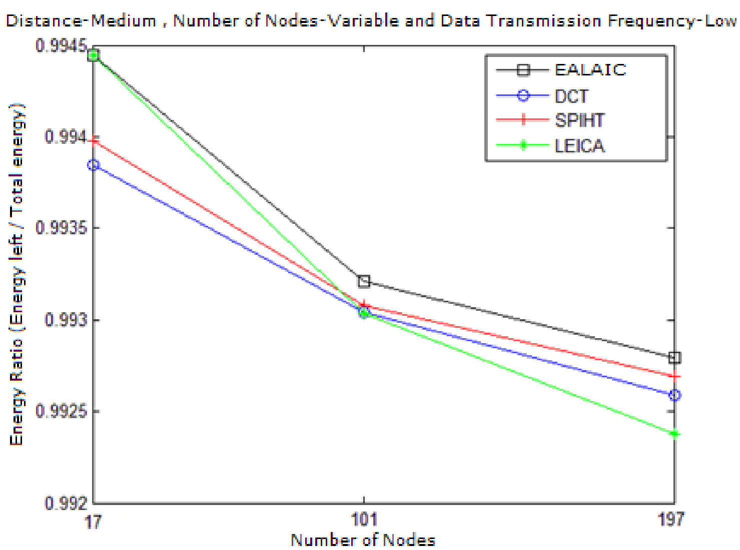

Fig. 15. Scenario: number of nodes versus energy rate graphic of four methods in the case that “Distance”-medium and “Data Transmission Frequency”-low

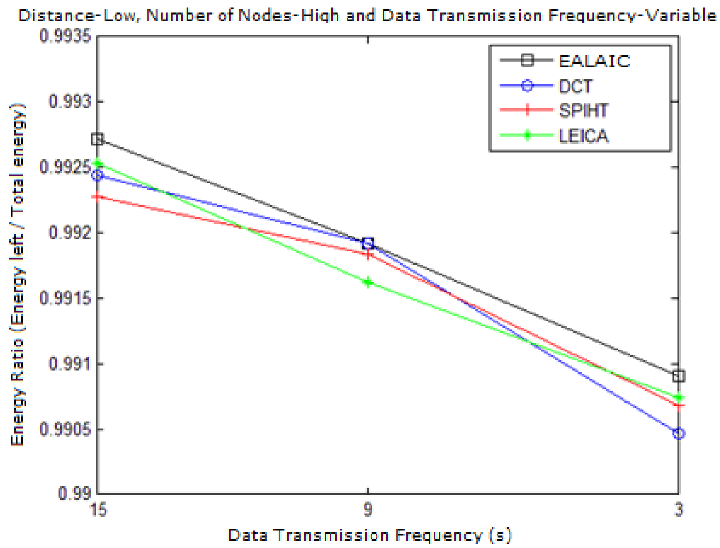

Fig. 16. Scenario: data transmission frequency versus energy rate graphic of four methods in the case that "Distance"-low and "Number of Nodes"-high

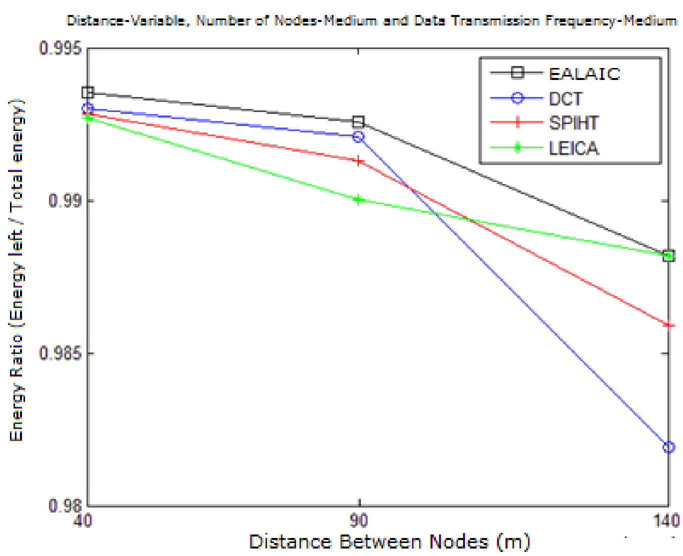

Fig. 17. Scenario: distance versus energy rate graphic of four methods in the case that "Number of Nodes"-medium and "Data Transmission Frequency"-medium

3.4. End to End Delay

Every packet produced in different scenarios is analyzed to obtain end to end delay. In this works, the average of the time to leave the source and reach the target for every packet

Table 9. Scenario: energy rates of five methods with respect to data transmission frequency in the case that "Distance"-low and "Number of Nodes"-high

Data Transmission Frequency (sec)	Energy Rate DCT	SPIHT	LEICA	EALAIC	Without Compression
15	0.9924413	0.9922819	0.9925320	0.9927140	0.9905598
9	0.9919207	0.9918407	0.9916191	0.9919207	0.9885940
3	0.9904621	0.9906785	0.9907414	0.9909013	0.9852178

Table 10. Scenario: energy rates of five methods with respect to distance in the case that "Number of Nodes"-medium and "Data Transmission Frequency"-medium

Distance (m)	Energy Rate DCT	SPIHT	LEICA	EALAIC	Without Compression
40	0.9929828	0.9928449	0.9926847	0.9935465	0.9897579
90	0.9920975	0.9912844	0.9900279	0.9925456	0.9545897
140	0.9819125	0.9859102	0.9881926	0.9881926	0.9325489

which reaches its target correctly is considered. This operation, taking the average time, is repeated separately for each algorithm (DCT, SPIHT, LEICA, and EALAIC) and the packet transmission path is designed in the same manner for every algorithm. That is, in the simulations realized for the same network, the path followed by the packets is the same for every algorithm. The compression times of the image compression algorithms are: DCT in 54.843 ms, SPIHT in 57.968 ms, and LEICA in 54.707 ms.

The time required for a packet to reach its target according to the scenario with 17 nodes is given in Table 11 for each algorithm. EALAIC decided DCT as the most energy-efficient image compression algorithm in this scenario and used it for compression.

Table 11. End to end transmission time of a packet for a scenario with 17 nodes according to the used methods

	Used Method DCT	SPIHT	LEICA	EALAIC
Elapsed Time (ms)	403,800	406,925	403,664	404,488

It is shown in Table 11 that EALAIC has better end to end delay value than SPIHT and worse than DCT and LEICA. The reason is that EALAIC uses the best algorithm it selected at every turn according to the network conditions and the compression times of these algorithms are different. Therefore, having varying values for different scenarios is natural.

3.5. Comparison of the Methods in terms of Energy Consumption

The methods of the referenced studies and the developed method EALAIC are compared in terms of the energy consumption which occurs while the image is compressed and transmitted. The same network model is used in the comparisons (distance between nodes is low, number of nodes is high, and data transmission frequency is variable). The average energy consumption of DCT [5], SPIHT [54], and LEICA [41] methods are calculated. Similarly, the average energy consumption of EALAIC depending on time is calculated using the mentioned network model.

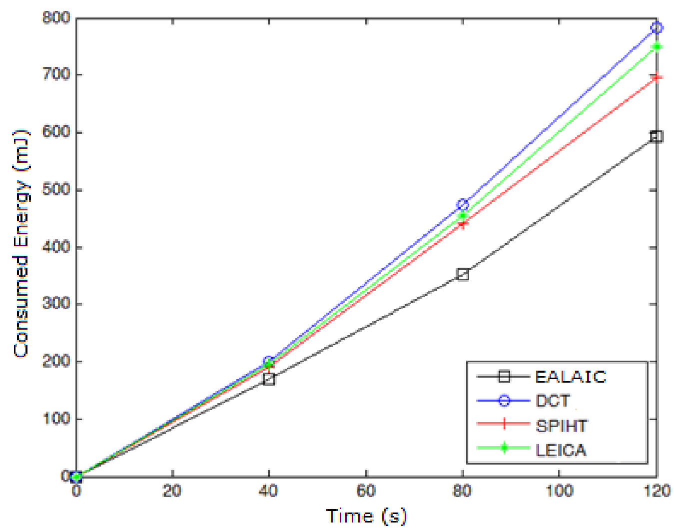

Fig. 18. Comparison of four methods based on the sample scenario depending on time

Figure 18 gives the comparison about time-dependent energy consumption of a node for EALAIC and other methods (DCT [5], SPIHT [54], and LEICA [41]) based on the network model in the sample scenario. The methods have worked for certain times and the average energy consumption of the network is calculated. Accordingly, It is seen that EALAIC consumes 103mJ less energy than the other methods.

This situation can be expressed clearly in terms of the energy consumption rates as: the value 1000 joules can be used approximately 47.6 hours by the least energy consuming algorithm, SPIHT on the average and it can be used by EALAIC for 55.5 hours. A node that uses EALAIC developed according to SPIHT has 7.9 hours more lifetime.

The proposed energy-efficient image compression-based approach was also compared by the state-of-the-art in order to show its performance. The existing papers were compare in Table 12 concerning the consumed energy.

Table 12. Comparison of the state-of-the-art

Reference	Year	Method	Consumed Energy
[43]	2011	Wavelet based image compression	more than 500 mJ
[17]	2015	Compressed sensing based image transmission	350-400 mJ
[31]	2018	Image segmentation	360-380 mJ
Proposed	2020	Adaptive image compression	100-200 mJ

4. Conclusion

A more effective method than the existing popular compression techniques used for WMSN has been proposed in this paper. The solution of the energy efficiency problem is given to be applied in the application layer. The proposed algorithm is different from the others since it decides the compression algorithm to be used through the parameters “distance between nodes”, “number of nodes”, and “data transmission frequency”. Therefore, the most suitable compression algorithm is selected instantly and maximum efficiency is provided. The method decides which algorithm to use according to the instant network conditions and so, it consumes less energy than the traditional methods that uses the same compression method for every condition. EALAIC provides 51% energy save for the stationary networks according to the methods without compression, and 36% energy save for the mobile networks. Also, for stationary networks, it saves 3% energy according to SPIHT, 3.6% save according to LEICA, and 4% save according to DCT. As for mobile networks it saves 2.7% energy according to SPIHT, 3.1% save according to LEICA, and 3.4% save according to DCT. It is seen that EALAIC prolongs the lifetime of every node by 7.9 hours on the average when 1000-joule energy is assigned to every node.

The proposed application layer method related to energy efficiency based on image compression can be combined with the energy-aware methods of other layers and a hybrid network with longer lifetime can be designed in the future works. Additionally, the efficiency of the proposed method can be tested by higher resolution cameras and the method can be generalized considering the resolution as an additional parameter.

References

1. Abd El Kader, M.E.E.D., Youssif, A.A., Ghalwash, A.Z.: Energy Aware and Adaptive Cross-Layer Scheme for Video Transmission Over Wireless Sensor Networks. IEEE Sensors Journal 16(21), 7792–7802 (nov 2016)
2. Abraham, A., Narendra, G.K.: Energy Aware Priority-Based Secure Image Transmission in Wireless Sensor Networks. In: 2012 8th International Conference on Wireless Communications, Networking and Mobile Computing. pp. 1–4 (2012), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6478513
3. Ahmed, N., Natarajan, T., Rao, K.: Discrete Cosine Transform. IEEE Transactions on Computers C-23(1), 90–93 (jan 1974), http://ieeexplore.ieee.org/document/1672377/
4. Akyildiz, I., Melodia, T., Chowdhury, K.: A survey on wireless multimedia sensor networks. Computer Networks 51(4), 921–960 (2007), http://linkinghub.elsevier.com/retrieve/pii/S1389128606002751

5. Amutha, R., Phamila, Y.: Energy efficient image compression scheme using ZonalDCT for wireless sensor networks. In: IET Chennai 3rd International Conference on Sustainable Energy and Intelligent Systems (SEISCON 2012). pp. 408–414. Institution of Engineering and Technology (2012), http://digital-library.theiet.org/content/conferences/10.1049/cp.2012.2247
6. Ben-Othman, J., Diagne, S., Mokdad, L., Yahya, B.: Performance evaluation of a hybrid MAC protocol for wireless sensor networks. In: Proceedings of the 13th ACM international conference on Modeling, analysis, and simulation of wireless and mobile systems - MSWIM '10. p. 327. ACM Press, New York (2010)
7. Ben-Othman, J., Yahya, B.: Energy efficient and QoS based routing protocol for wireless sensor networks. Journal of Parallel and Distributed Computing 70(8), 849–857 (2010)
8. Cobo, L., Quintero, A., Pierre, S.: Ant-based routing for wireless multimedia sensor networks using multiple QoS metrics. Computer Networks 54(17), 2991–3010 (2010)
9. Din, I.U., Hassan, S., Almogren, A., Ayub, F., Guizani, M.: PUC: Packet Update Caching for energy efficient IoT-based Information-Centric Networking. Future Generation Computer Systems (2019)
10. Ehsan, S., Hamdaoui, B.: A Survey on Energy-Efficient Routing Techniques with QoS Assurances for Wireless Multimedia Sensor Networks. IEEE Communications Surveys & Tutorials 14(2), 265–278 (2012), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=5714976
11. Er-Rouidi, M., Moudni, H., Mouncif, H., Merbouha, A.: A balanced energy consumption in mobile ad hoc network. In: Procedia Computer Science. vol. 151, pp. 1182–1187. Elsevier B.V. (2019)
12. Farrag, O., Younis, M., D'Amico, W.: MAC Support for Wireless Multimedia Sensor Networks. In: GLOBECOM 2009 - 2009 IEEE Global Telecommunications Conference. pp. 1–6. IEEE (nov 2009)
13. Ghazalian, R., Aghagolzadeh, A., Andargoli, S.M.H.: Energy consumption minimization in wireless visual sensor networks using convex optimization. In: 7'th International Symposium on Telecommunications (IST'2014). pp. 312–315. IEEE (sep 2014), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=7000720
14. Gürses, E., Akan, Ö.B.: Multimedia communication in wireless sensor networks. Annales Des Télécommunications 60(7-8), 872–900
15. Hamid, Z., Hussain, F.B.: QoS in Wireless Multimedia Sensor Networks: A Layered and Cross-Layered Approach. Wireless Personal Communications 75(1), 729–757 (mar 2014), http://link.springer.com/10.1007/s11277-013-1389-0
16. Haseeb, K., Islam, N., Almogren, A., Ud Din, I., Almajed, H.N., Guizani, N.: Secret Sharing-Based Energy-Aware and Multi-Hop Routing Protocol for IoT Based WSNs. IEEE Access 7, 79980–79988 (2019)
17. Hemalatha, R., Radha, S., Sudharsan, S.: Energy-efficient image transmission in wireless multimedia sensor networks using block-based Compressive Sensing. Computers and Electrical Engineering 44, 67–79 (may 2015)
18. Hoon Kim, Sung-Gi Min: Priority-based QoS MAC protocol for wireless sensor networks. In: 2009 IEEE International Symposium on Parallel & Distributed Processing. pp. 1–8. IEEE (may 2009)
19. Hossain, M.S., You, X., Xiao, W., Lu, J., Song, E.: QoS-oriented multimedia transmission using multipath routing. Future Generation Computer Systems 99, 226–234 (oct 2019)
20. K, P.K., Govindaraj, E.: Quality enhancement with fault tolerant embedding in video transmission over WMSNs in 802.11e WLAN. Ad Hoc Networks 88, 18–31 (may 2019)
21. Kandris, D., Tsagkaropoulos, M., Politis, I., Tzes, A., Kotsopoulos, S.: Energy efficient and perceived QoS aware video routing over Wireless Multimedia Sensor Networks. Ad Hoc Networks 9(4), 591–607 (2011)

22. Kumar S., A.A., Ovsthus, K., Kristensen., L.M.: An Industrial Perspective on Wireless Sensor Networks — A Survey of Requirements, Protocols, and Challenges. IEEE Communications Surveys & Tutorials 16(3), 1391–1412 (2014)
23. Li, B.Y., Chuang, P.J.: Geographic energy-aware non-interfering multipath routing for multimedia transmission in wireless sensor networks. Information Sciences 249, 24–37 (2013)
24. Lin, M.s., Leu, J.s., Yu, W.c., Yu, M.c., Wu, J.l.C.: On Transmission Efficiency of the Multimedia Service over IEEE 802 . 15 . 4 Wireless Sensor Networks. In: Advanced Communication Technology (ICACT), 2011 13th International Conference on. pp. 184–189 (2011)
25. Liu, J., Wang, D., Zhao, J.: An energy-efficient distributed adaptive cooperative routing in wireless multimedia sensor networks. In: 2019 IEEE 11th International Conference on Communication Software and Networks, ICCSN 2019. pp. 163–169. Institute of Electrical and Electronics Engineers Inc. (jun 2019)
26. Liu, X.: An optimal-distance-based transmission strategy for lifetime maximization of wireless sensor networks. IEEE Sensors Journal 15(6), 3484–3491 (2015)
27. Ma, T., Hempel, M., Peng, D., Sharif, H.: A Survey of Energy-Efficient Compression and Communication Techniques for Multimedia in Resource Constrained Systems. IEEE Communications Surveys & Tutorials 15(3), 963–972 (2013), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6226793
28. Magli, E., Mancin, M., Merello, L.: Low-complexity video compression for wireless sensor networks. In: 2003 International Conference on Multimedia and Expo. ICME '03. Proceedings (Cat. No.03TH8698). vol. 3, pp. III–585. IEEE (2003), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=1221379
29. Mainwaring, A., Culler, D., Polastre, J., Szewczyk, R., Anderson, J.: Wireless Sensor Networks for Habitat Monitoring. Proceedings of the 1st {ACM} International Workshop on Wireless Sensor Networks and Applications pp. 88–97 (2002), http://doi.acm.org/10.1145/570738.570751
30. Mulugeta, T., Shu, L., Hauswirth, M., Chen, M., Hara, T., Nishio, S.: Secured two phase geographic forwarding protocol in wireless multimedia sensor networks. In: GLOBECOM - IEEE Global Telecommunications Conference (2010)
31. Pal, T., DasBit, S.: A low-overhead adaptive image compression technique for energy-constrained WMSN. Computers and Electrical Engineering 70, 594–615 (aug 2018)
32. Palaskar, S.P., Chavhan, N.A.: Design and Implementation of Energy Efficient Node Data Transmission by Using Mobile Sink Node. In: 2014 Fourth International Conference on Communication Systems and Network Technologies. pp. 79–82. IEEE (apr 2014), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6821361
33. Pudlewski, S., Prasanna, A., Melodia, T.: Compressed-Sensing-Enabled Video Streaming for Wireless Multimedia Sensor Networks. IEEE Transactions on Mobile Computing 11(6), 1060–1072 (jun 2012), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6188348
34. Rahimi, M., Baer, R., Iroezi, O.I., Garcia, J.C., Warrior, J., Estrin, D., Srivastava, M.: Cyclops: In Situ Image Sensing and Interpretation in Wireless Sensor Networks. In: Proceedings of the 3rd international conference on Embedded networked sensor systems - SenSys '05. pp. 192–204 (2005), http://doi.acm.org/10.1145/1098918.1098939
35. Said, A., Pearlman, W.A.: A new, fast, and efficient image codec based on set partitioning in hierarchical trees. {IEEE} Transactions on Circuits and Systems for Video Technology 6(3), 243–250 (1996)
36. Savidge, L., Huang Lee, Aghajan, H., Goldsmith, A.: QoS-based geographic routing for event-driven image sensor networks. In: 2nd International Conference on Broadband Networks, 2005. pp. 68–77. IEEE
37. Saxena, N., Roy, A., Shin, J.: Dynamic duty cycle and adaptive contention window based QoS-MAC protocol for wireless multimedia sensor networks. Computer Networks 52(13), 2532–2542 (2008)

38. Senturk, A., Kara, R.: An analysis of image compression techniques in wireless multimedia sensor networks. Tehnicki Vjesnik 23(6) (2016)
39. Shapiro, J.: Embedded image coding using zerotrees of wavelet coefficients. IEEE Transactions on Signal Processing 41(12), 3445–3462 (1993), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=258085
40. Suh, C., Mir, Z.H., Ko, Y.B.: Design and implementation of enhanced IEEE 802.15.4 for supporting multimedia service in Wireless Sensor Networks. Computer Networks 52(13), 2568–2581 (2008)
41. Sun, E., Shen, X., Chen, H.: A low energy image compression and transmission in wireless multimedia sensor networks. In: Procedia Engineering. vol. 15, pp. 3604–3610 (2011)
42. Thomos, N., Boulgouris, N.V., Strintzis, M.G.: Optimized transmission of JPEG2000 streams over wireless channels. IEEE Transactions on Image Processing 15(1), 54–67 (2006)
43. Tian, F., Liu, J., Sun, E., Wang, C.: An energy efficient and load balancing distributed image compression algorithm in WMSNs. In: Procedia Engineering. vol. 15, pp. 3421–3427. Elsevier (jan 2011)
44. Toor, A., ul Islam, S., Sohail, N., Akhunzada, A., Boudjadar, J., Khattak, H.A., Din, I.U., Rodrigues, J.J.: Energy and performance aware fog computing: A case of DVFS and green renewable energy. Future Generation Computer Systems 101, 1112–1121 (dec 2019)
45. Ul Islam, S., Khattak, H.A., Pierson, J.M., Din, I.U., Almogren, A., Guizani, M., Zuair, M.: Leveraging utilization as performance metric for CDN enabled energy efficient internet of things. Measurement: Journal of the International Measurement Confederation 147 (dec 2019)
46. Ullah, U., Khan, A., Zareei, M., Ali, I., Khattak, H.A., Din, I.U.: Energy-Effective Cooperative and Reliable Delivery Routing Protocols for Underwater Wireless Sensor Networks. Energies 12(13), 2630 (jul 2019), https://www.mdpi.com/1996-1073/12/13/2630
47. Ur Rehman, Y.A., Tariq, M., Sato, T.: A novel energy efficient object detection and image transmission approach for wireless multimedia sensor networks. IEEE Sensors Journal 16(15), 5942–5949 (aug 2016)
48. Wang, P., Dai, R., Akyildiz, I.F.: Collaborative Data Compression Using Clustered Source Coding for Wireless Multimedia Sensor Networks. In: 2010 Proceedings IEEE INFOCOM. pp. 1–9. IEEE (mar 2010), http://ieeexplore.ieee.org/document/5462034/
49. Wei, Z., Lijuan, S., Jian, G., Linfeng, L.: Image compression scheme based on PCA for wireless multimedia sensor networks. The Journal of China Universities of Posts and Telecommunications 23(1), 22–30 (2016)
50. Xiaojiang Du, X., Hsiao-Hwa Chen, H.h.: Security in wireless sensor networks. IEEE Wireless Communications 15(4), 60–66 (aug 2008), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4599222
51. Yan, X., Li, L., An, F.: Multi-constrained routing in wireless multimedia sensor networks. In: 2009 International Conference on Wireless Communications & Signal Processing. pp. 1–5. IEEE (nov 2009)
52. Yao, Y., Cao, Q., Vasilakos, A.V.: EDAL: An Energy-Efficient, Delay-Aware, and Lifetime-Balancing Data Collection Protocol for Heterogeneous Wireless Sensor Networks. IEEE/ACM Transactions on Networking 23(3), 810–823 (jun 2015), http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6757018
53. Zaineldin, H., Elhosseini, M.A., Ali, H.A.: Image compression algorithms in wireless multimedia sensor networks: A survey (2015)
54. ZainEldin, H., Elhosseini, M.A., Ali, H.A.: A modified listless strip based SPIHT for wireless multimedia sensor networks. Computers & Electrical Engineering 56, 519–532 (2016)
55. Zeeshan, M., Majid, M., Nizami, I.F., Anwar, S.M., Ud Din, I., Khurram Khan, M.: A newly developed ground truth dataset for visual saliency in videos. IEEE Access 6, 20855–20867 (apr 2018)
56. Zhuo, X., Loo, K., Cosmas, J., Yip, P.: Distributed video coding in wireless multimedia sensor network for multimedia broadcasting (2008)

Dr. Arafat Senturk graduated in Computer Engineering from the Faculty of Engineering of Atilim University in 2009 and earned a PhD in Electrical and Computer Engineering from the Enstitute of Science of Duzce University in 2017. He has been worked as a research assistant at Duzce University for six years and working as assistant prof. since 2017 at the same institution. His interests include wireless sensor networks. https://orcid.org/0000-0002-9005-3565

Dr. Resul Kara received the B.S. and M.S. degrees in electrical and electronics engineering from Gazi University, Ankara in 1996 and in1999, respectively and Ph.D. degrees in electronics engineering from Sakarya University, Sakarya, in 2009. He worked as an assistant professor from 2009 to 2012 and as an associate professor from 2012 to 2017 with the Computer Engineering Department in Duzce University, Duzce. Since 2017, he has been a Professor with the same department. His research interests include computer networks, MANETs, wireless communication and network security. https://orcid.org/0000-0001-8902-6837

Dr. Ibrahim Ozcelik was born in Izmit, Kocaeli, Turkey in 1973. He received the B.S. degree in electric and electronic engineering from Karadeniz Technical University, Trabzon, in 1995 and M.S. and Ph.D. degrees in electronic engineering from Sakarya University, Sakarya, in 1997 and in 2002, respectively. He worked as a research assistant from 1995 to 2002 and as an assistant professor from 2002 to 2012 and as an associate professor from 2012 to 2020 with the Computer Engineering Department in Sakarya University. Since 2020, he has been a Professor with the same department. He is the author of more than 30 articles. His research interests include computer networks, VANETs, industrial communication systems, cyber security and SCADA security. https://orcid.org/0000-0001-9985-5268

Received: November 24, 2019; Accepted: May 23, 2020.