TELKOMNIKA Indonesian Journal of Electrical Engineering
Vol.12, No.1, January 2014, pp. 661 ~ 668
DOI: http://dx.doi.org/10.11591/telkomnika.v12i1.3739

Distributed Image Compression and Transmission Scheme in Wireless Multimedia Sensor Networks

Enyan Sun*[1,2], Xuanjing Shen[1], Haipeng Chen[1], Chuanyun Wang[2]
[1]College of Computer Science and Technology, Jilin University, Changchun, China
[2]Schoolof Computer Science, Shenyang Aerospace University, Shenyang, China
(+86) 02489723892
*Corresponding author, e-mail: sunenyan418418@163.com

Abstract

Wireless multimedia sensor networks will have a variety of applications. Meanwhile, WMSNs produce a large amount of image data. JPEG2000 is the popular image compression standard and have some advantages. However, JPEG2000 is also high complexity and cannot be realized in an individual senor node which is limited in memory capacity, computation power and energy. Distributed image compression and transmission scheme is proposed to overcome the problem of scarce resources of the individual sensor node and uneven energy consumption. Simulation experiments show that DICT can more evenly consume the energy of senor nodes in WMSNs and prolong the network lifetime comparable to centralized image compression and transmission scheme.

Keywords: *wireless multimedia sensor networks, distributed image compression, DWT, energy consumption, network lifetime*

1. Introduction

The rapid development of sensors, MEMS, embedded computing, inexpensive CMOS cameras and microphones has resulted in the advent of Wireless Multimedia Sensor Networks (WMSNs). WMSNs are networks of wirelessly interconnected sensor nodes equipped with mutimedia devices, such as cameras and microphones. WMSNs are the high version of Wireless sensor networks, which not only can obtain, process and transmit scalar data, but also can capture, process and transmit multimedia data such as audio, video and still image. WMSNs will have more application domains [1-5].

Meanwhile, multimedia information can produce a large amount of data, and it puts forward challenges for the sensor nodes whose resources are limited in computation, memery and energy. Nowadays, the main information which is transmitted in WMSNs is still image. The still image compression standard is JPEG which is based on discrete consine transform and JPEG2000 which is based on discrete wavelet transform. JPEG2000 have some advantages such as progressive transmission and region of interest coding. JPEG2000 have better perfomance than JPEG when an image is compressed at high compression rate [6].

However, the computation complexity of JPEG2000 needs more memory and energy consumption, which will quickly deplete single node' energy. Further, it will break up the whole network and shorten the network lifetime. To solve the above problem, Distributed image compression has been proposed and become the research hotspot of WMSNs. Distributed image compression is based upon the theory of parallel computation and makes more sensor nodes participate in image compression, which lessens the computation burden of single sensor node and balances the energy consumption of sensor nodes in WMSNs. Ultimately, distributed image compression can prelong the network lifetime.

2. The Proposed Method

Huaming Wu et al. [7] firstly proposed the concept of distributed image compression in resource-constrained multihop wireless networks. By exploiting the characteristics of DWT, they proposed a distributed image compression scheme where sensor nodes compress an image while forwarding it the destination. However, when the source node is near from the destination

Received June 29, 2013; Revised August 25, 2013; Accepted September 17, 2013

node, the last hop sensor nodes from the destination node will too early be dead due to undertake too much image compression.

Qin Lu at al. [8] proposed the architecture for energy efficient image transmission in WSNs. All normal sensor nodes are organized into normal clusters. The camera-equipped nodes form their own clusters in which the camera-equipped node works as the cluster head and normal sensor nodes works as cluster members. The camera-equipped node sends raw images to cluster members. Cluster members share image compression tasks and send compressed images to normal cluster heads. The architecture can prolong the lifetime of network in the case of the sensor nodes deployed densely. However, there is only one camera-equipped node which is selected in the simulation experiment.

Mohsen Nasri et al. [9] proposed efficient JPEG2000 image compression scheme for multihop wireless networks. DWT, quantization and entropy encoding which JPEG2000 includes are realized on different clusters to balance normal sensor nodes' energy consumption and prolong the network lifetime. However, the communication scheme between different clusters does not conform to traditional clustering protocol.

3. Research Method

3.1. Energy Consumption Model of Wireless Multimedia Sensor Networks

Energy consumption distribution is in assembling state in the tranditional wireless sensor networks. Energy consumption mainly comes from the wireless transmission and energy which is consumed in data processing is generally ignored. However, energy consumption of image capturing, processing, and transmission is almost equivalent in the WMSNs, which is distributed evenly. Energy which is spent on image processing can not be simply ignored. JPEG2000 image compression standard is composed of discrete wavelet transform, quantization, embedded coding and code-stream ordering. Energy which is consumed on compressing a bit data is calculated by formula (1).

$$E_{comp} = E_{DWT} \bullet \sum_{L=1}^{L_0} (\tfrac{1}{4})^{L-1} + E_{code} \tag{1}$$

E_{DWT} represents the energy consumption for 2D discrete wavelet transform of one bit data, and E_{code} represents the energy consuption for encoding of one bit data. L_0 is the level of DWT. When the value of L_0 is 5, the image compression can obtain good performace. $E_{DWT}$and E_{code} are respectively 220nJ/bit and 20nJ/bit. [8]

In wireless multimedia sensor networks, the node A transmits k bits to the node B and the distance between two nodes is d. The energy that the node A consumes is computed through the formula (2). The energy that the node B consumes is computed through formula (3).

$$E_{TX}(k,d) = E_{TX-elec}(k) + E_{TX-amp}(k,d) = \begin{cases} k \bullet E_{elec} + k \bullet \varepsilon_{fs} \bullet d^2, d < d_0 \\ k \bullet E_{elec} + k \bullet \varepsilon_{amp} \bullet d^4, d \geq d_0 \end{cases} \tag{2}$$

$$E_{RX}(k) = k \bullet E_{elec} \tag{3}$$

E_{elec} is the energy consumption of the electric circuit when the node transmits or receives data. E_{elec} is 50nJ/bit. $E_{TX-amp}(k,d)$ is the energy consumption of the amplifier. ε_{fs} and ε_{amp} respectively is 10pJ/bit/m^2 and 0.0013pJ/bit/m^4. The value of d_0 is about 87m [10].

3.2. Energy Consumption Analysis in Traditional Image Compression and Transmission Scheme

When analyzing the communication problem among nodes, nodes are classified into transmitting nodes and receiving nodes. Generally, there are two transmission schemes in

WMSNs. The transmitting node may directly transmit raw image to the receiving node, which is define as the Direct Transmission Scheme (DTS). The transmitting node firstly compress raw images, and transmit compressed images to the receiving node, which is difined as the Indirect Transmission Scheme (ITS). Assume that the size of a raw grey image is M*N pixels and d represents the distance between the transmitting node and the receiving node. The total energy consumption of the transmitting node and the receiving node by adopting DTS is computed by formula (4).

$$E_{direct} = E_{TX}(M \times N \times 8, d) + T_{RX}(M \times N \times 8) \quad (4)$$

The energy consumption of image compression is computed by formua (5).

$$E_{compression} = M \times N \times 8 \times E_{comp} \quad (5)$$

The energy consumption of a compressed image transmission is computed by formula (6). br represents image compression bit rate.

$$E_{communication} = E_{TX}(M \times N \times br, d) + T_{RX}(M \times N \times br) \quad (6)$$

The total energy consumption of the transmitting node and the receiving node by adopting ITS is computed by formula (7).

$$E_{indirect} = E_{compression} + E_{communication} \quad (7)$$

Figure 1 shows that the total energy consumption of DTS and ITS are related to the distance between the transmitting node and the receiving node. During the intra-cluster communication, the camera node is used as the transmitting node and the cluster head is used as the receiving node. When the camera node is near the cluster head, the energy consupmtion of DTS is farther less than the energy consumption of ITS. E_{direct} equals to $E_{indirect}$ when the value of d is about 114m. The communication distance between the cluster head and cluster members is near, and DTS is better than ITS. It demonstrates that the energy is consumpted less by directly transmittting raw image.

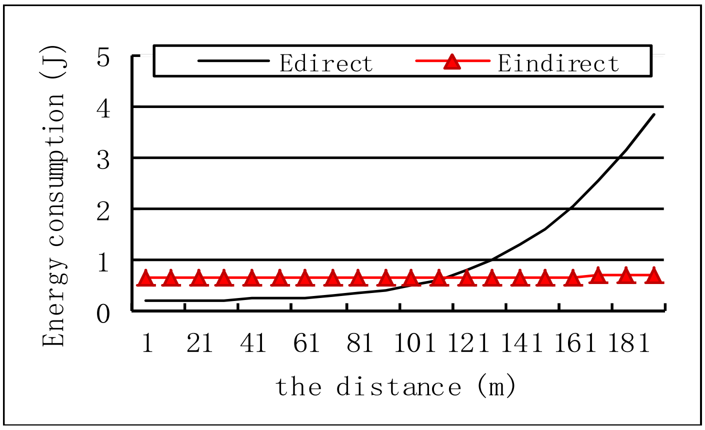


Figure 1. Energy consumption distribution of DTS and ITS

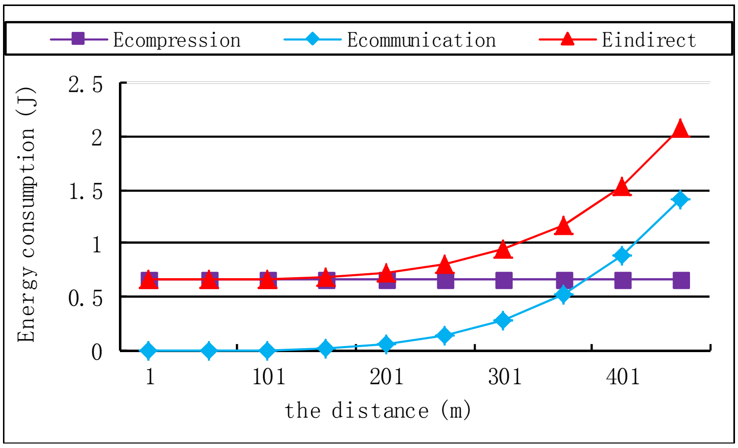


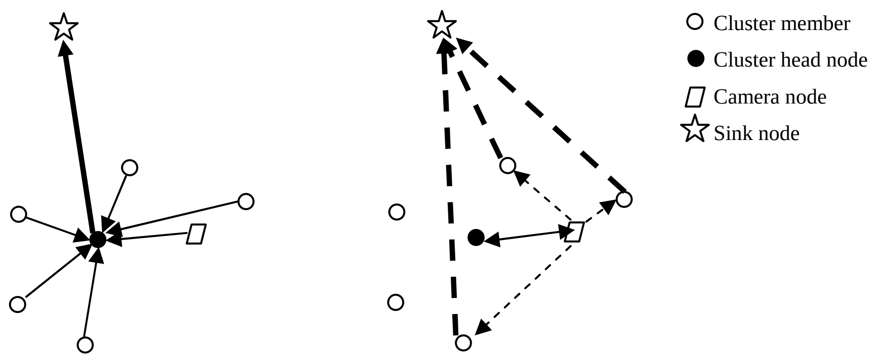
Figure 2. Energy consumption distribution of image compression and transmission

During the inter-cluster commnunication, the cluster head has to communicate to the sink and the cluster head is used as the transmiting node and the sink is used as the receiving node. Generally, cluster members and cluster heads are far from the sink, and the energy consumption using DTS increases quicky along with the increasing distance. ITS is better than DTS. Figure 2 shows the energy consumption distribution of image compression and image transmission using ITS. When the distance is less than 372m, image compression consumes most of energy using ITS.

Image compression may consume most energy of sensor nodes. More nodes can take part in image compression among a cluster, which lessens the individual node' burden of computation and energy consumption. Based the above idea, distributed image compression and transmission scheme is proposed.

3.3. Distributed Image Compression and Transmission Scheme

Network model is decribed as the following. Assume there exit two kinds of sensor nodes which are normal sensor nodes and camera nodes in WMSNs. The number of camera nodes are less than the number of normal senor nodes, because the price of camera nodes is high and camera nodes have larger sensing radius. Images which camera nodes capture are little correlation. Both normal sensor nodes and camera nodes can adjust their transmission radius dynamically. Camera nodes can capture, process and transmit images and normal nodes can process and transmit images.



(a) LEACH (b) DICT

Figure 3. The data transmission path

The tranditional hierachical routing protocol is LEACH protocol [11,12]. Figure 3(a) shows the data transmission path of LEACH. Normal sensor node is divided into the Cluster Head (CH) and the cluster member (CM) in the network. Normal sensor nodes produce CHs by Competition. Normal sensor nodes which are not CHs become CMs. CMs transmit their collected data to the CH. The CH fuses these data and transmit them to the sink which is far from the cluster. The camera node may join in near cluster and act as CM. However, a huge amount of image information which the camera node produces will deplete the energy of the CH.

Distributed Image Compression and Transmission scheme (DICT) is proposed to balance the energy consumption of nodes in WMSNs.The operation of DICT is controlled by a round. The main works which are finished in one round are described as the following. Normal sensor nodes can cluster by Leach protocol. Figure 3(b) shows the data transmission path of DICT. Camera nodes can join in neighbour cluster in according to signal strength and act as CMs. Camera nodes partition the raw image into blocks and transmit blocks to several CMs within a cluster. Each CM compresses each image block and directly sends the compressed image block the sink. The whole image is compressed and transmitted by several normal senor nodes with one cluster to lessen the burden of the single sensor node and balance the energy consumption of sensor nodes. Furthermore, it prelongs the network lifetime. The detailed operation of DICT is decripted as the following.

(1) Normal nodes set up clusters

All normal senor nodes are organized into clusters by standard LEACH protocol. The selected CH is responsible for coordinating the data communication within it cluster.The LEACH protocol is introduced in reference [11].

(2) Camera nodes join in the neighbour cluster

All CHs are in receiving state. The camera nodes broadcast the hello message with a fixed transmission radius. After the CH receives the hello message, the CH replies an ack message. If the camera node receives more one ack messages, the camera node join the neighbor cluster in according to RSSI. If the camera node does not receive any ack messages, the camera continues to broadcast the hello messgae with an increasing transmission radius. At last, all camera nodes join in the neighbour cluster.

(3) Coordination of the CH and the camera node

After the camera node capture images according to the actual needs, the camera node notifies to the CH and transmit the basic image information and the number of captured images to the CH. The CH collects the basic information of every CM within it cluster. The CH selects a subset of CMs which are ready to participate in distribued image compression and transmission. The residual energy of subset of CMs must higher than Elowest which is enough to finish tasks of image and transmission. The number of selected CMs is defined as S1. S1 is related to the number of images which the camera nodes capture. The CH sends the above scheme to camera node.

(4) Camera nodes distribute tasks of image compression and transmission

After the camera receives the above scheme which CH sends,the camera node partitions the image into S1 blocks according to the above scheme and send raw image blocks to a subset of CMs. Communication distance within a cluster is generally near and Section 3.2 have proved that energy consumption is less by directly transmitting raw image.

(5) CMs compress and transmit image blocks

After a subset of CMs receive the image blocks, these CMs compress the image blocks using JPEG2000 and directly send compressed image blocks the sink.Section 3.2 have analyzed that image compression can consume most of energy of sensor nodes. Therefore, more CMs are needed to participate in image compression. Long distance communication between the cluster and the sink can consume a lot of energy. Multiple CMs directly transmit compressed image blocks to the sink to balance the energy consumption of every sensor nodes in WMSNs.

(6) The sink reconstructs the image

The sink collects all image blocks and decompresses image blocks. Finally, the sink reconstructs the whole images.Refence [13] have proved that the image quality can be tolerated when an image is partitioned into image blocks and these blocks are compressed by JPEG2000.

4. Results and Analysis

Simulation experiments are designed to evaluate the energy consumption balance and the network lifetime of DICT. Two other image compression and transmission schemes are introduced to compare results. Camera Compressing Image Scheme (CCIS) is that the camera node compresses captured images and sends compressed images to the CH. The CH collects all compressed images from camera nodes within it cluster and sends these images to the sink.

Cluster Head compressing Image Scheme (CHIS) is that the camera sends raw images to the CH. The CH compresses all raw images from camera nodes within it cluster and send these compressed images to the sink.

4.1. Simulation Experiment of Energy Consumption Balance

Assume that camera nodes and normal senor nodes are deployed randomly at rectangular region which size is 200*200m^2. The position of the sink is (150m,200m). The initial energy of camera nodes and normal sensor nodes is respectively 100J and 50J. The number of camera nodes is 10 and the number of normal sensor nodes is 100. During the round, each camera node capture 4 grey images which is 512*512. Figure 4 and Figure 5 show the distribution of residual energy of normal senor nodes and camera nodes after CCIS, CHIS and DICT run 30 rounds.

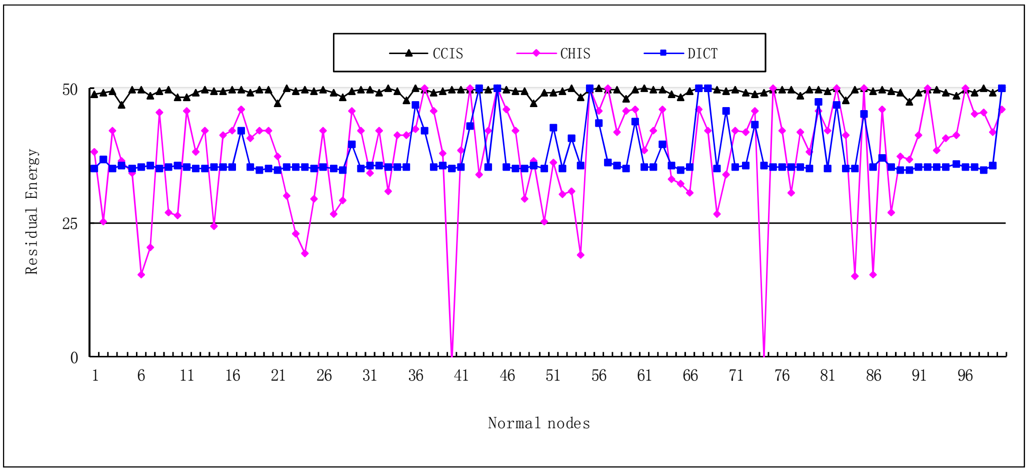


Figure 4. The distribution of residual energy of normal nodes

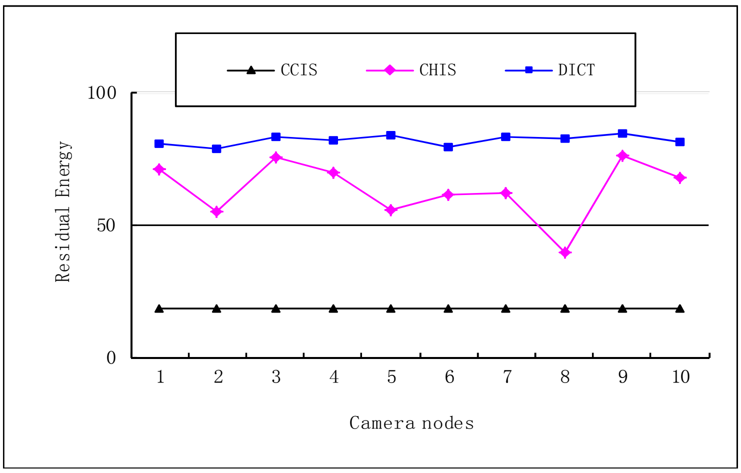


Figure 5. The distribution of residual energy of camera nodes

Residual energy of normal sensor nodes using CCIS is the highest in Figure 4, because normal senor nodes do not participate in image compression. Figure 5 shows that Residual energy of camera nodes using CCIS is the lowest, which shortens the lifetime of camera nodes. Figure 4 shows DICT can consume more evenly than CHIS, because more normal sensor nodes participate in image compression and transmission. And Figure 5 shows that the residual energy of camera nodes using DICT is the highest. It illustrates that some tasks of camera nodes is distributed among normal senor nodes so that camera nodes consume less energy.

4.2. Simulation Experiment of the Network Lifetime

Assume that camera nodes and normal senor nodes are deployed randomly at rectangular region which size is 300*300m^2. The position of the sink is (150m,350m). The initial energy of camera nodes and normal sensor nodes is respectively 100 and 50J. The number of camera nodes is 10 and the number of normal sensor nodes is from 30 to 180. During the round, each camera node capture 4 grey images which is 512*512. When 70 percent of normal senor nodes are dead or one camera node is dead, the lifetime of WMSNs is considered be over.

Figure 6 shows the network lifetime using CCIS,CHIS and DICT. With normal sensor nodes increasing, the network lifetime using CHIS and DICT increases obviously because more sensor nodes participate in images compression. When the number of normal senor nodes is 180, the the network lifetime using DICT is the longest. It profits from more sensor nodes sharing image compression and transmission tasks of camera nodes and cluster heads.

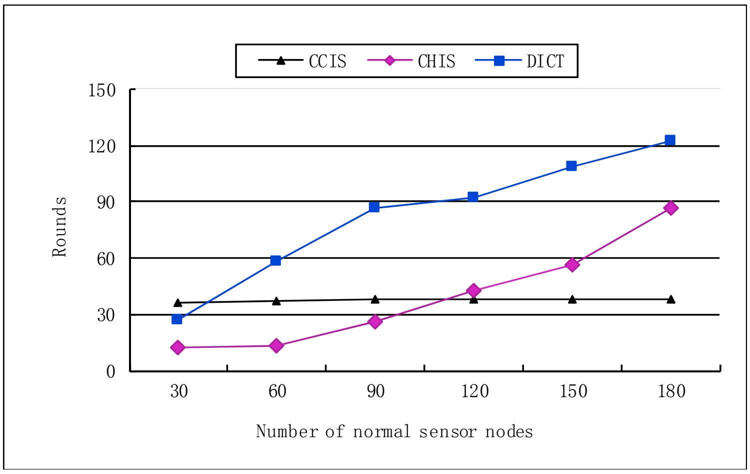


Figure 6. The network lifetime of WMSNs

5. Conclusion

This paper has studied the distributed image compression and transmission scheme in WMSNs. DICT is proposed to lessen the individual sensor node's burden of computation, memery and energy. DICT can balance the energy consumption of sensor nodes in networks and extend the network lifetime. Simulation experiment shows that DICT is better than centralized image compression and transmission scheme such as CCIS and CHIS in the energy consumption balance and the network lifetime. As the future work, we will apply the ditributed image and transmission scheme into the actual the system of WMSNs and verify the feasibility of DICT.

References

[1] Akyildiz, Ian F, Weilian Su, Yogesh Sankarasubramaniam, and Erdal Cayirci. Wireless sensor networks: a survey. *Computer networks*. 2002; 38(4): 393-422.
[2] Ian F Akyildiz, Tommaso Melodia, Kaushik R. Chowdhury. A survey on wireless multimedia sensor networks. *Computer Networks*. 2007; 51(4): 921-960.

[3] Akyildiz, Ian F, Tommaso Melodia, and Kaushik R. Chowdhury. *Wireless multimedia sensornetworks: applications and testbeds*. Proceedings of the IEEE. 2008; 96(10): 1588-1605.
[4] Soro, Stanislava, and Wendi Heinzelman. A survey of visual sensor networks. *Advances in Multimedia*. 2009.
[5] Misra, Satyajayant, Martin Reisslein, and Guoliang Xue. A survey of multimedia streaming in wireless sensor networks. *Communications Surveys & Tutorials*. 2008; 10(4): 18-39.
[6] Li Wern Chew, Li-Minn Ang, Kah Phooi Seng. *Survey of Image Compression Algorithms in Wireless Sensor Networks*. International Symposium on Information Technology 2008, ITSim. Kuala Lumpur. 2008; 3: 1-9.
[7] Huaming Wu, Alhussein A Abouzeid. Energy efficient distributed image compression in resource-constrainedmultihop wireless networks. *Computer Networks*. 2005; 28(14): 1658-1668.
[8] Qin Lu, Xiangbin Ye, Liebo Du. *An Architecture for Energy Efficient Image Transmission in WSNs.* International Conference on Networks Security, Wireless Communications and Trusted Computing (NSWCTC), 2009; 1: 296-299.
[9] Mohsen Nasri, Abdelhamid Helali, Halim Sghaier, Hassen Maaref. Efficient JPEG 2000 image compression scheme for multihop wireless networks. *TELKOMNIKA Telecommunication, Computing, Electronics and Control*. 2011; 9(2): 311-318.
[10] Alicewang, Wendi B. Heinzelman, Amit Sinha and Anantha P. Chandrakasan. Energy-Scalable Protocols for Battery-Operated MicroSensor Networks. *Journal of VLSI Signal Processing*. 2001; 29: 223-237.
[11] Wendi Rabiner Heinzelman, Anantha Chandrakasan, and Hari Balakrishnan. *Energy-Efficient Communication Protocol for Wireless Microsensor Networks*. The 33rd Annual Hawaii International Conference on System Sciences (HICSS-33). Maui. 2000; 223-232.
[12] Zhang, Shaoping, and Hong Pei. A Two-hop Collaborative Localization Algorithm for Wireless Sensor Networks. *TELKOMNIKA Indonesian Journal of Electrical Engineering*. 2013; 11(5) : 2432-2441.
[13] LU Qin, LUO Wu-sheng, HUBing. Multi-node cooperative JPEG2000 implementation based on neighbor clusters in wireless sensor networks. *Optics and Precision Engineering*. 2010; 18(1): 240-247.