A Distributed Image Compression Algorithm Based on a Genetic Algorithm Based Clustering Infrastructure for Mobile Wireless Multimedia Sensor Networks

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Abstract: In this study, a distributed image compression algorithm which is executed on a genetic algorithm based clustering infrastructure is proposed for mobile wireless multimedia sensor networks. Because of the mobility, some nodes can locate far away from their cluster heads which cause a requirement for reconstruction of the clusters. The proposed genetic algorithm based clustering infrastructure is designed by considering the uniformity of the clusters, speed of the nodes, energy consumption and distance to base station parameters. When a huge amount of image data is needed to be transmitted via the sensor nodes, it must be compressed distributedly because of the limited energy resources. In this study, by considering nodes mobility, image data is transmitted distributedly to the base station via genetic algorithm based clustering infrastructure. The proposed system and the centralized approach are compared for energy consumption, network lifetime and image quality parameters on different mobility models of the sensor nodes.

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1. Introduction

Advancements in low cost and multifunctional sensor nodes made them applicable in many different types of application areas such as military, environmental, commercial and health. Sensor networks are composed of number of tiny sensor nodes which have sensing, processing and communicating capabilities. There are many different types of nodes which can sense different types of data such as temperature, moisture, pressure, noise, velocity, mobility and image (Alaybeyoglu et al., 2009).

While transmitting process of the small amount of data via the nodes is simple, when the amount of data becomes higher such as in transmitting process of the image or video data, some compression techniques are needed in order to decrease the workloads of the sensor nodes. Because of the energy constraints of sensor nodes, rather than making a one node compress the huge amount of data centrally, compression process should be distributed among the nodes while transmitting the data to the base station.

To increase network lifetime, algorithms which are designed for sensor network applications should be energy efficient. Clustering is one of the most commonly used technique for energy efficiency. In this technique, nodes are grouped as member and head nodes. Member nodes send their sensed data to their head nodes rather than sending it directly to the base station which locates much far away than their head nodes. Hence, by using clustering technique, energy consumption is decreased and network lifetime is increased.

When nodes are mobile in sensor network, clusters are required to be updated periodically. Because by the time member nodes locate far away from their current head nodes and distance to the base station also changes. In this study, in order to provide optimum clusters, genetic algorithm based clustering approach is proposed.

Main contribution of the proposed system is implementing both of the genetic algorithm based clustering and the distributed image compression systems on a mobile wireless multimedia sensor network. Because of the nodes mobility, clusters are required to be regenerated. Genetic algorithm of whose the parameters of fitness function is determined with the consideration of nodes mobility is used for updating the clusters. The proposed image compression algorithm is executed on the genetic algorithm based clustering infrastructure. Figure 1 shows the components of the proposed system.

The rest of the paper is organized as follows: Related works are given in Section 2. Background that includes genetic algorithm and image compression subsections is given in Section 3. Section 4 describes the system model that includes network and mobility models. The proposed system is described in Section 5. Simulation results are given in Section 6 and lastly conclusion is given in Section 7.

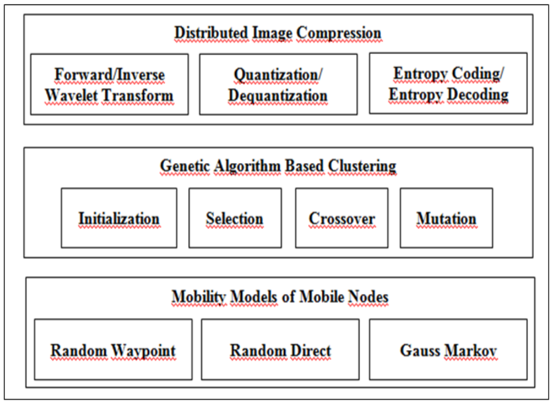


Figure 1. Components of the Proposed System

2. Related Works

One of the most important constraints on sensor networks is limited energy resource. In order to decrease energy consumption, several clustering techniques are proposed in literature. There are many heuristics which are proposed for constructing energy efficient clusters such as genetic algorithm which is one of the evolutionary algorithms that mimics the process of natural evolution (Basaran and Alaybeyoglu, 2013). (Kumar and Panwar, 2012) proposes an improvement over an existing hierarchical cluster based routing by using a genetic algorithm to decide the number of clusters, the cluster heads, their members and the communication scheme. (Khalil and Attea, 2011) aims to achieve a better arrangement between the network stability and longevity. The crucial step to accomplish this idea is reformulating the fitness function used in the genetic algorithm. (Sachdov and Nygard, 2009) proposes a new genetic algorithm that uses floating point numbers to represent chromosomes and claim to have a better and scalable solution. (Heidari and Movaghar, 2009) proposes a genetic algorithm to solve sensor network optimization problem which is for to reduce energy consumption, to decide number of clusters, to select cluster heads and to bind sensor nodes to a cluster. (Ferentinos and Tsiligiris, 2007) proposes a multi-objective genetic algorithm for dynamic and adaptive wireless sensors aiming to reduce the total energy consumption by taking into consideration application specific requirements.

There are also some studies for transmitting image data among the sensor nodes (Wu and Abouzeid, 2005), (Karthikeyan et al., 2013), (Dabestani and Main, 2013), (Tian et al., 2011), (Sun et al, 2011). In all of these studies, nodes are assumed to be stationary. In (Wu and Abouzeid, 2005), with the aim of transmitting the image data distributedly, image data is splited into blocks and each node in the cluster sends the intermediate results of the wavelet transformed data to its head node which then sends the compressed data by combining the intermediate results to the head of the next cluster. (Karthikeyan et al., 2013) uses embedded block coding method in addition to discrete wavelet transform. In (Dabestani and Main, 2013), distributed vector quatization is used and codebook is created by applying neural network of adaptive resonance theory. In (Tian et al., 2011), load balancing of the nodes is considered while transmitting the image data. In (Sun et al, 2011), the captured image data is partitioned into region of interest on which the monitored objects appear. This region is compressed at a low compression ratio while the bad image quality of tiles are compressed at high compression ratio.

3. Background

In this section, the fundamentals of the proposed system are described in two subsections namely genetic algorithm and image compression.

3.1 Genetic Algorithm

Genetic Algorithm technique is one of the evolutionary algorithms that mimics the process of natural evolution (Wikipedia, 2012). Population, Fitness Function, Selection, Crossover and Mutation are the main steps of genetic algorithm. Populations are set of solutions and include chromosomes that are composed of series of numbers. Fitness function measures the quality and the performance of a solution. This step should include the most important factors that affect the performance of the system. In Selection step, chromosomes with larger fitness values are selected to be participated in reproduction step. In crossover step, new generation is developed by passing information from one generation to next. Newly generated chromosomes include portion of information from their parents. Lastly in mutation step, parts of the chromosomes are changed randomly and the aim of this step is to avoid much similarity in population (Alaybeyoglu, 2011), (Romoozi and Ebraimpour, 2010).

3.2 Image Compression

Neighboring pixels are correlated with each other in most of the image data which can be represented with less number of bits by eliminating the redundant data (Wu and Abouzeid, 2005). The proposed image compression algorithm is based on Discrete Wavelet Transform which is composed of Forward / Inverse Wavelet Transform, Quantization / Dequantization, Entropy Coding / Decoding.

With Discrete Wavelet Transform, the signal is decomposed into the signal frequencies and then they are coded. In the proposed system, oktav-band decomposition technique is used. According to this technique, low and high pass filters are applied to the signal.

First of all, low pass filter is applied to the each row of the data and then low frequency data at rows are obtained. Similiarly, high pass filter is applied to the same row of data and by this way high and low frequencies of data are seperated. This operation which is applied on rows is called "1D Wavelet Transform". The same filtering operation is applied to each coloums of intermediate output data and this whole process is called "2D Wavelet Transform". At the end of these steps, four subbands are obtained, namely: LL(low-low), HL(high-low), LH (low-high) and HH(high-high) (Wu and Abouzeid, 2005).

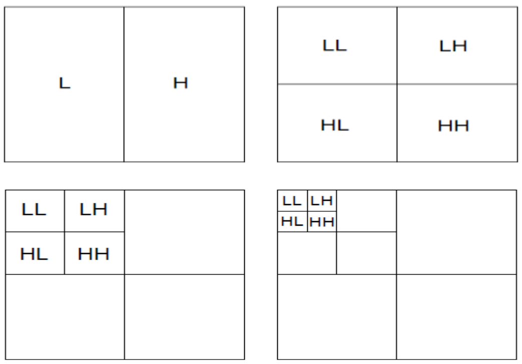


Figure 2. Discrete Wavelet Transform

After discrete wavelet transform is performed on image data, vector quantization and entropy coding steps are implemented.

4. System Model

In this section, network model of the system and the mobility models of the mobile nodes are described in detail.

4.1 Network Model

The sensor network is modelled as an undirected graph $G(V,E)$ with the vertices (V) representing the sensor nodes and the edges (E) representing the communication links between these nodes (Alaybeyoglu, 2011). Links are symmetric. Thus if there is a link from u to v, there exists a reverse link from v to u. Some assumptions are made about the sensor networks as in the studies (Chen et al., 2009), (Dagdeviren and Erciyes, 2010), (Jung et al., 2011), (Lin et al., 2012): Each node has an unique node id. The nodes are stationary and time synchronized. Each node knows its location and the location of its immediate neighbours.

4.2 Mobility Models

There mobility models namely; Random Waypoint, Random Direct and Gauss Markov are used for nodes movement scenarios.

- **Random Waypoint Model**

In Random waypoint mobility model (Alaybeyoglu et al., 2009), each node travels from a starting coordinate to a random ending coordinate with a randomly generated constant velocity. The velocity is randomly picked from [0, V*max*] and as the V*max* value increases, average velocity V*avg*= (0 + V*max*)/2 of the nodes also increases. When a node reaches the destination point, it waits for a time before arriving in the next destination (Bai and Helmy, 2004).

- **Random Direction Model**

In Random Direction mobility model (Alaybeyoglu et al., 2009), instead of choosing a random destination, nodes choose a random direction which reaches the boundary of the simulation area. When a node reaches the boundary of the simulation area, it waits for a time and it chooses a new direction to travel (Bai and Helmy, 2004).

- **Gauss-Markov Model**

In RWM and RDM, unrealistic behaviors such as sharp turns, sudden stops, and sudden accelerations may frequently occur. Gauss-Markov Model(GMM) is proposed to prevent these problems (Alaybeyoglu et al., 2009). In this mobility model, the next velocity of the node is determined in accordance with the node's previous velocity(Bai and Helmy, 2004).

5. The Proposed System

The proposed system is composed of two subsystems namely; genetic algorithm based clustering infrastructure and distributed image compression algorithm. In this section, these systems both of which are proposed for mobile wireless multimedia sensor networks are described in details.

5.1 A Genetic Algorithm Based Clustering Technique for Mobile Wireless Multimedia Sensor Networks

Because of the nodes mobility, the distances of the nodes to other nodes, to head nodes and to base station change by the time. This causes requirement for considerable improvements on the clustering approaches which are designed for static wireless networks.

In the proposed system, genetic algoritm is executed by base station and the calculated clustering information is distributed to the nodes in network area. Nodes send their speed, energy and location information to the base station periodically. When a mobile node moves to very far away from its current head node, it sends its sensed data directly to the base station rather than sending it to its cluster head node till reclustering is performed (Saranji and Kar, 2011).

In the proposed genetic algorithm based clustering infrastructure, each population member is represented with binary numbers (0 and 1) and each bit represents the nodes which is called gene. Cluster head nodes are represented with 1 while member nodes are represented with 0. Each produced chromose is a candidate for the solution and the suitability of this solution is determined with the fitness function. The chromose which has the highest fitness value is the best candidate to be the solution. Five parameters namely, cluster uniformity, speed, energy consumption, density and distance to base station are used in the fitness function (Türkoğlu, 2013).

Uniformity of Clusters (UC): Optimum number of nodes that should be in the network area in accordance with the number of head nodes. Uniformity is very important because when a number of nodes in a cluster is very high, cluster head consumes its energy very quickly. Uniformity of cluster parameter is calculated by dividing the total number of nodes in the network area to the total number of head nodes.

TN:Total number of nodes, MN:Number of member nodes, HN: Number of head nodes

$$TN = MN + HN$$

$$\textit{Uniformity of the Clusters} = TN / HN$$

Speed (S): As the speed of a node increases, the probability of selecting that node as a head node decreases. Because, fast moving node leaves the cluster more frequently than the other nodes.

$$Speed = \sum_{i=1}^{TN} Speed(i)$$

Energy Consumption (EC): This parameter represents the total energy consumption of nodes during data transmission. If we assume that there are n number of clusters and k number of nodes in each clusters, energy consumption of the nodes can be calculated with following formula:

$$EC = \left(n\,x \sum_{i=1}^{k} ET(i)\right) + \left(\sum_{i=1}^{n} ER(n)\right) + \left(\sum_{i=1}^{n} EA(n)\right)$$

In this formula, ET represents the energy consumption during the message transmission from member nodes to head nodes, ER represents the energy consumption during message receive and EA represents the energy consumption during the data aggregation process of the head node.

Distance to Base Station (DBS): This parameter is calculated by adding the distance of the head node to the base station and distances of the each member nodes to their head nodes [24].

$$\textit{Distance to Base Station} = \sum_{i=1}^{MN} d(i) + \sum_{j=1}^{HN} d(j)$$

Finally the fitness function of the system can be calculated as:

$$\textit{Fitness Function} = (\alpha\, UC + \beta\, S + \gamma\, EC + \mu\, DBS)$$

α, β, γ ve μ coefficients represent the effects of the parameters on fitness function.

In the selection step of the algorithm, chromosomes are selected from the existing chromosomes in order to produce new populations. In crossover step, multipoint crossover technique in which the crossing points are determined randomly is used. Mutation is applied to the chromosomes which are newly produced after crossover step. In mutation step, some of the bits in chromosome are changed. In other words, some head nodes become member nodes and some member nodes become head nodes.

5.2 Distributed Image Compression Algorithm

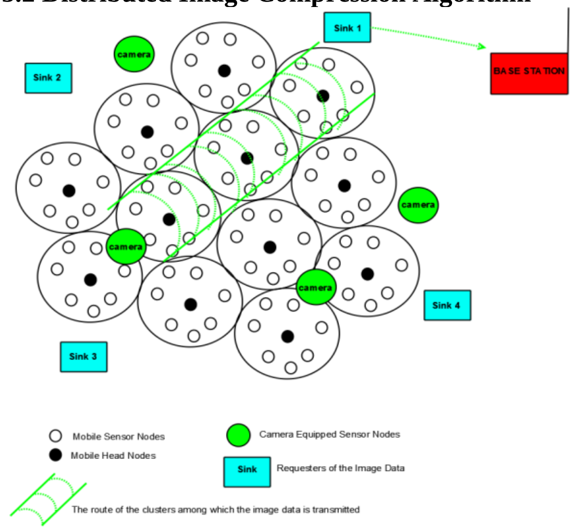


Figure 3. Clusters Through The Route of Source to Destination

Because of the energy constraints of sensor nodes, transmission of huge amount of data like image and video, should be distributed among the sensor nodes rather than making only one node transmit the data. By distributing the workloads of sensor nodes, energy consumption is balanced and network lifetime is increased. With the proposed system, image data is compressed distributedly while it is transmitted to the base station. The main difference of the proposed system from the study proposed in [8] is considering the nodes mobility and reconstructing the clustering infrastructure dynamically. Another difference of the proposed system is data can be distributed from multisource to multidestination rather than single source to single destination as in [8]. Because the nodes are mobile, image data is transmitted distributedly among the genetic algorithm based clustering infrastructure. The camera node which sensed the the requested image data, sends it to the destination via the clusters that locate through the direction of the destination. General idea of the proposed system for transmitting the image data from camera node to destination is shown in Figure 3. Details of transmitting the image data by compressing it with distributed discrete wavelet transform based technique is shown in Figure 4.

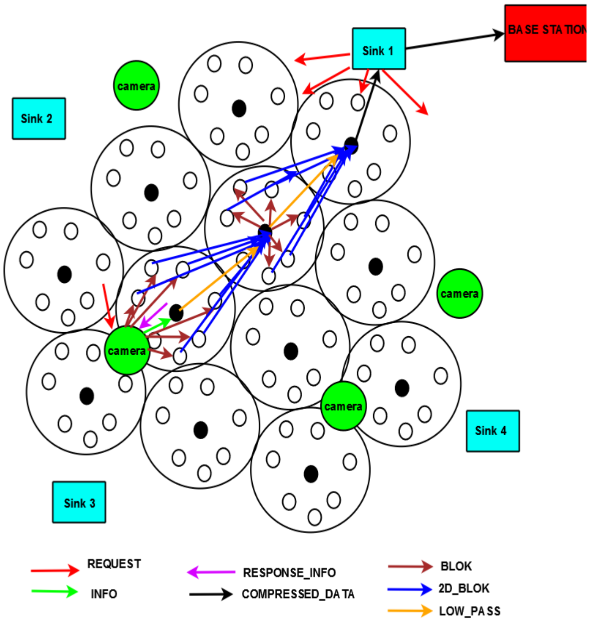


Figure 4. Transmitting the Image Data by Compressing with Distributed Discrete Wavelet Transform

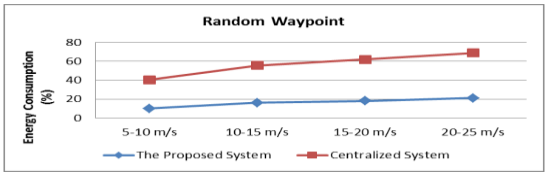
In the proposed system, when a sink node requires a data, it floods a REQUEST message to the network. A camera node which receives this message, checks its sensed data to decide whether they match or not. If the requested data and sensed data match, camera node send INFO message to the head node which locates closest to the direction of the destination node to get information about the member nodes of the head node. When the head node receives INFO message, it replies with RESPONSE_INFO message which includes the information about member nodes that will take roll in the process of of distributed discrete wavelet transform. Camera node splits the image data into blocks and sends BLOCK message including block information to the member nodes which then apply 2D discrete wavelet transform on these blocks and send intermediate results seperately with 2D_BLOCK message to the next head node that locates closest to the direction of the sink node. The head node that receives 2D_BLOCK message, sends BLOCK message including the low frequencies of each block to its member nodes which then apply 2D discrete wavelet transform. Head node sends LOW_PASS message including LH, HL and HH parts of the blocks to the next head node. This process continues till the required quality and related sink node are reached. Quantization and entropy coding steps are processed by each node centrally and these steps are held before data exchange [8].

6. Performance Analysis

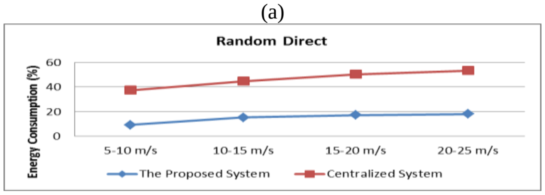
The proposed and the compared systems are implemented in ns-2 network simulator. Nodes mobility scenarios that include mobility models namely Random Waypoint, Random Direct and Gauss Markov are generated with ANSim. IEEE 802.11 radio and MAC standards are used for low layer protocols. The proposed system and the centralized approach are compared in terms of energy consumption, system lifetime and image quality parameters on different mobility models and speeds. Range of speeds are determined as 5-10m/s, 10-15m/s and 15-20m/s. Image quality is determined by calculating the peak signal to noise ratio (PSNR)[8]. 256x256 Lena image data is used for performance analysis. Nodes are distributed randomly to the 5100x1200m network area. Communication range and initial energy of each node are 250m and 100J respectively. Energy consumptions of nodes during message transmission and message receive are 0.660W and 0.395W respectively.

Figure 5 shows energy consumption of the proposed and centralized systems for different mobility models and speeds. Energy consumption ratio of the proposed system can be calculated with following formula:

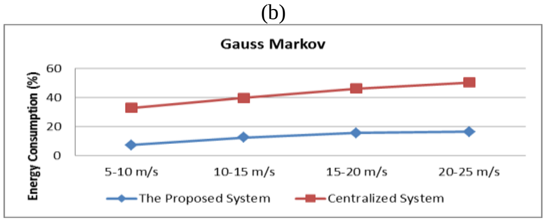
Energy Consumption (%) = ((Initial Energy– Remaining Energy) / (Initial Energy)) x100



(a)



(b)



(c)

Figure 5. Energy Consumption (%) comparison of the proposed and the centralized systems for different mobility models and the speeds

As it can be seen from Figure 5, for each of the mobility models, as the speed of the node increases, energy consumption also increases. The reason for this is, as the nodes move far away from their head nodes, frequency of reconstructing the clusters also increases. When we compare the mobility models, it can be seen that while the best performance for energy consumption is obtained in gauss markov mobility model, the worst is obtained in random waypoint mobility model. This is because of the reason that, in gauss markov mobility model nodes move also to the borders of the network area rather than moving to the center. By this way, more balanced clustering infrastructure can be achieved.

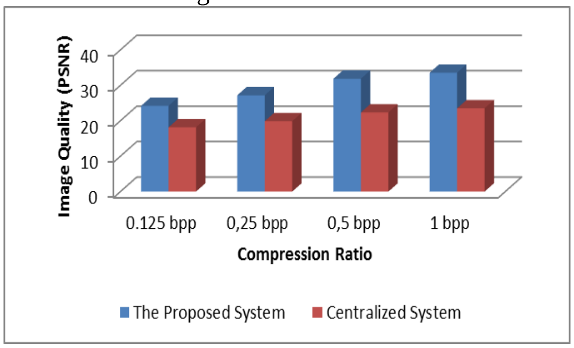


Figure 6. Image Quality Comparison of the proposed and the centralized systems for Random Waypoint Mobility Model

Figure 6 shows the quality comparison of the proposed and centralized systems for random waypoint mobility model. It can be seen from the figure that the proposed system performs best for each of the compression ratio.

System lifetime of the proposed system and centralized approach is compared for random waypoint mobility model in Figure 7. As it can be seen from the figure, system lifetime of the proposed system is the highest for each of the total node numbers. The reason for this is distributing the workload of image transmission process among the sensor nodes. By this way, energy consumptions of the nodes are balanced.

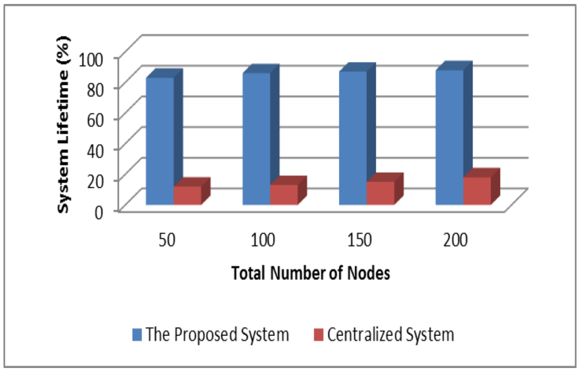


Figure 7. System Lifetime (%) Comparison of the proposed and the centralized systems for Random Waypoint Mobility Model

7. Conclusion

In this study, a system for transmitting and compressing the image data distributedly on a genetic algorithm based clustering infrastructure is proposed for mobile wireless multimedia sensor networks. The system is composed of two subsystems namely genetic algorithm based clustering infrastucture and distributed image compression and transmission. Considering nodes mobility, dynamic clustering infrastructure and distributed image compression are the main contributions of the proposed system. Besides these, the proposed system is implemented on three different mobility models and compared to centralized approach in terms of energy consumption, image quality and system lifetime parameters. When the simulation results are analyzed, it can be seen that for each of the parameters, the proposed system performs best. It can also be seen from the simulation results that energy consumption performance of the nodes is high when they move with gauss markov mobility model. Lastly, as the nodes increase their speeds, energy consumption also increases in both of the proposed system and centralized approach.

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