Energy Saving Strategy for Video-based Wireless Sensor Networks Under Field Coverage Preservation

D. Pescaru[1], C. Istin[1], D. Curiac[1], A. Doboli[2]
[1] Faculty of Computers and Automation, "Politehinca" University of Timisoara, Romania,
Dan.Pescaru@cs.upt.ro, Codruta.Istin@cs.upt.ro, Daniel.Curiac@aut.upt.ro
[2] Department of ECE, State University of New York at Stony Brook, USA,
adoboli@ece.sunysb.edu

***Abstract*- The demand for video-based Wireless Sensor Networks (WSN) applications has significantly increased. Different from conventional sensor networks, video WSN imply a directional sensing model, complex in-node processing, and large data transfer, thus high clock frequencies and significant radio transmission time. Reducing energy consumption is a key requirement for reliable applications. We propose in this paper a novel energy saving method based on redundant node deactivation while preserving field coverage.**

I. INTRODUCTION

Wireless Sensor Networks (WSN) are large collections of tiny sensing devices deployed in an area of interest. In general, WSN are densely deployed for offering fine-grained monitoring [1]. WSN are expected to address critical applications, like environmental monitoring, emergency search and rescue operations, robotics, and many more. A mandatory step towards developing real-life WSN is building nodes that can efficiently gather data, process it, send it to the central unit (sink), and communicate with other nodes in the network. Traditional WSNs use nodes with different sensor types, depending on the area of interest. Recently, a video-based WSN captured increasingly the interest of the research community.

Video-based WSNs have several distinctive features that differentiate them from traditional WSNs. In addition to the usual acoustic and thermal sensors, they integrate a low energy video camera. Hence, the processes of data collection, aggregation, and transmission to the central unit are different for video-based WSN. Significant research has been done in data aggregation and routing algorithms for transmitting only the interesting part of the entire image [2]. Hard time constraints have been addressed in [3].

Since video-based WSNs are mainly used in surveillance applications, field coverage is an important issue. The coverage problem is difficult due to the fact that the gathered data is not in the sensor's vicinity, and involves the field of view for each sensor [4]. The field of view is defined as the maximum volume visible from the camera [5]. The camera therefore can capture images of distant areas and objects that appear within the camera's depth of field (the distance between the nearest and the farthest object that the camera can capture sharply). Reference [6] presents an analysis of the correlation between coverage and the degree of connectivity, and proposes three coverage levels: full coverage with connectivity, partial coverage with connectivity, and coverage with constrained connectivity. Full coverage with connectivity means that every location in the field is covered by at least one node and information at this location can be reported to the sink. Partial coverage with connectivity requires less stringent coverage and connectivity guarantee. It is appropriate when a certain percent of the collected data provides sufficient information for the application. In constrained coverage with connectivity, the maximum size of the area in which an event can occur without being reported to the fusion center must be bounded.

Reference [7] analyzes the deployment and redeployment for reducing energy consumption. When building a video-based WSN in an inaccessible area, sensor deployment is realized through scattering. The position of the sensors is not totally controllable and coverage is very important. One sensor's field of view may be overlapped with another field of view, and nodes might have redundantly collected data. This is important for reducing the cost of transmission and energy consumption.

A promising solution to save energy in video-based networks is presented in [8]. The authors propose a coordination algorithm for topology maintenance. The algorithm adaptively elects node coordinators from all the nodes in the network, and rotates them in time. Coordinators stay awake and perform multi-hop packet routing within the ad hoc network, while other nodes remain in power saving mode and periodically check if they should wake up and become coordinators. Another solution for energy saving is presented in [2]. The method addresses the way the sensing task is partitioned among sensors. It proposes an image fusion algorithms based on epipolar line constraint to fuse the received partial images at the sink.

This paper proposes a novel method for preserving a network's coverage and lifetime by saving energy. This strategy implies turning off redundant nodes and when necessary turning them again on. This algorithm is important in the cases with limited infrastructure or vulnerable field areas and for which deployment is based on sensors scattering. The performed experiments show the efficiency of the strategy for saving energy while preserving the WSN coverage.

1-4244-2577-8/08/$20.00 ©2008 IEEE

The rest of the paper is organized as follows. The next section reviews the related work on energy saving in WSNs and video-based WSNs. Section 3 describes the problems of topology control and defines the covering metrics. Section 4 describes the proposed energy saving strategy. Section 5 presents experimental results, and demonstrates field coverage preservation. Finally, Section 6 provides conclusions.

II. Energy Saving in Wireless Sensor Networks

A. Energy Saving Problem

Minimizing energy consumption to prolong the lifetime of the network is a major research challenge in wireless sensor networks. Researchers are currently exploring advanced techniques that look both into hardware and software optimizations for saving energy.

Hardware based approaches generally refer to the capability of nodes being turned off completely. This requires using a topology control algorithm that reconfigures the connections between nodes for avoiding data transmission through the nodes turned off, but still keeps the network connected. In Span [8], each node periodically decides whether to go to sleep or stay awake as a coordinator. A node volunteers to be a coordinator if two of its neighbors cannot communicate with each other directly or through an existing coordinator. Similar to this approach, [9] presents an algorithm that maintains for each node a count of the number of nodes within radio range. This information is obtained by listening to transmissions on the channel. A node switches between sleeping and listening with a randomized sleep time proportional to the number of nearby nodes. Hence, the number of listening nodes is constant. The two algorithms differ in that Span never keeps a node awake unless it is essential to connect two neighbors.

To maximize the overall network lifetime, [10] presents an algorithm that minimizes the routing energy by choosing paths through a multi-hop ad-hoc network. Nodes adjust their transmission power levels and select routes to optimize performance. Energy saving by dedicated routing methods is discussed in [11], where a technique based on Directed Diffusion is proposed. The authors describe Directed Diffusion routing and illustrate one instantiation of this paradigm for sensor query dissemination and processing. They show that using Directed Diffusion one can realize robust multi-path delivery, empirically adapt to a small subset of network paths, and achieve significant energy savings when intermediate nodes aggregate responses to queries. An interesting method for energy saving through routing is presented in [12]. It analyzes the lifetime extent of a wireless sensor network that employs periodic sensing. Lower and upper bounds on the network lifetime are computed, and the routing algorithms that lead to these bounds are also presented. For large sensor networks, the upper and the lower bounds on the network lifetime are relatively close (less than a few percents), leading thus to the conclusion that for such networks the choice of the routing protocol is largely irrelevant for maximizing the network lifetime, as long as some form of shortest paths are followed. Simulation results are presented to validate the theoretical results. Other approaches discuss the possibility of minimizing the energy consumed by each message [13] [14] [15]. This metric might unnecessarily overload some nodes causing them to die prematurely. Minimizing the variance in the power level of each node [16] is another possibility that saves energy. Minimizing the maximum energy drain of any node is a solution discussed in [17] and [18].

The work in [19] proposes an energy-efficient optimization approach to achieve tracking accuracy constrained by energy consumption. It enables reorganization of a wireless sensor networks, and includes three phases, prediction, localization, and recovery. The first phase uses a particle filter algorithm on the sink to forecast the future movement of the target. Then, the most energy efficient sensor nodes are awakened up to locate the target. Energy efficiency is calculated as the ratio of mutual information to energy consumption. The recovery phase is performed when the target is missed because of incorrect prediction of the target location, and is based on genetic algorithms.

B. Energy Saving in Video-based Wireless Sensor Networks

All techniques discussed so far can be applied to video-based WSNs with some specific constraints. Specific algorithms for saving energy have been also proposed. Reference [20] discusses a method that uses a hardware platform that can put a node to stand-by, but still allows traffic. Stand-by nodes do not gather information, but are able to route messages. This type of nodes allows the separate treating of the network aspects and image sensing.

The quality of images is a major reason for consuming processing power in video-based WSN. This is directly influenced by resolution and frame rates. A novel algorithm that implies image-processing techniques is presented in [2]. It aims to reduce the workload of individual sensors. Given the limited resources of sensor nodes, the approach exploits the redundancy among nodes by partitioning the sensing task to highly correlated sensors. For an object of interest, each sensor only captures and delivers a fraction of the entire scene. Then, the partial images are fused together for reconstructing the image. Experiments show that this approach achieves promising results. The authors offer detailed discussions about the effect of the variance for different algorithm parameters.

III. Topology and Field Coverage Metrics for Video-based Wireless Sensor Networks

The sensor nodes of a wireless sensor network are often deployed in an ad-hoc manner on an unplanned infrastructure without a priori knowledge of the location. Also, additional nodes might be redeployed any time both to maximize field coverage or to replace malfunctioning nodes. Thus, topology extraction after deployment is an important problem. Different solutions have been proposed for this problem, including those based on precise but expensive GPS and methods based on the receiving time and signal strength. These solutions cannot be applied for video-based WSNs mainly due to lack of information about the orientation of the sensor's cameras.

In [21] we proposed a solution for node localization based on video-field overlapping estimation. It starts with video images acquired from all network nodes. Then, it computes the video field overlapping, and extracts parameters, e.g., coordinate translation, rotation angles, and scaling factors. The solution matches image registration with static images gathered quasi-simultaneously after deployment. Fig. 1 depicts the field of view overlapping for a network with 40 nodes.

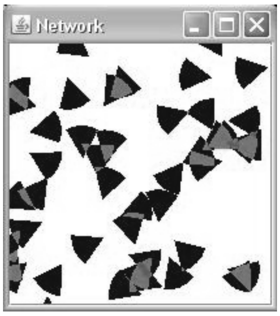

Figure 1. Field of View overlapping for a network with 40 nodes.

The proposed method assumes that all camera sensors are placed in the same horizontal planar surface, and all fields of view are projections on this surface. Another assumption is that the cameras have a limited view range. Indeed, in order to obtain an accurate perspective, a maximum range (DMax) was established considering the video sensor resolution and the size of the smaller targets of interest. The requirement is to capture at least N_p pixels of the target surface in an image. This means that the object of interest is considered to be in the field of view of the sensors only if the object is closer than the maximum range distance DMax. Then, an efficient field of view is modeled as an angle sector α of a circle with a radius DMax and centered in the node's position. Fig. 2 illustrates the modeling of efficient fields of view when the node orientation is an angle φ.

In order to describe WSN deployment efficiency, several metrics have been proposed [4][7]. While some of them are hard to apply to video-based WSNs, field coverage seams to be more appropriate. For redundant node deployment, the field coverage is the percent of the covered surface from the total deployment surface (CS/S). We selected this metric to evaluate the proposed energy saving strategy.

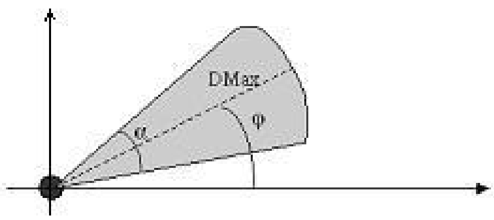

Figure 2. Efficient field of view.

IV. Energy Efficient Strategy Based on Field Coverage

Video based WSN are consuming more energy than traditional video-less sensors due to the need to process locally a part of the collected images. To increase the lifetime of video-based WSN, we propose an algorithm that detects redundancy and then turns off the less significant nodes with the possibility of reactivating them if necessary.

The algorithm has two phases: first, after deployment, the areas covered by more than one sensor are identified and the percentages of the overlapped areas are calculated so that the less significant redundant nodes can be turned off. In the second step, the nodes incapable of performing their required tasks are detected. To maintain coverage and to prolong the network lifetime, some nodes that were turned off in the first step are turned on now. This saves energy.

A. Redundant Nodes Selection Algorithm

Despite nodes being turned off, the covered area is not significantly affected and the lifetime of the network is prolonged. The intuitive motivation comes from the fact that in WSN, the number of scattered nodes is huge, up to 20 nodes/m^3 [22]. The proposed algorithm considers that a node is redundant only if the area covered by that node is also covered by at least one more node in a percentage of at least 70%. As nodes are scattered and their deployment cannot be precisely controlled, it is likely that for a large number of nodes some areas are covered by more than one or two fields of view from the sensors.

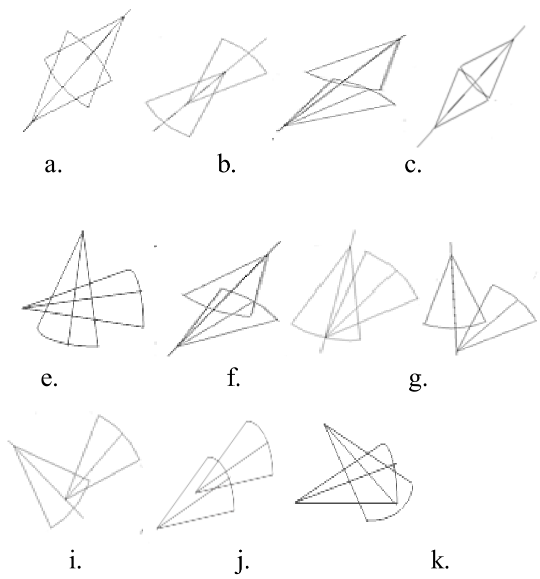

Figure 3. Relative positions of two sectors of circle.

In this case, the algorithm detects the intersection of all sensors and decides which sensor is the most insignificant. Only that sensor is turned off and this is done only in if the overlapping area for that sensor is greater than the threshold percentage.

Although the redundant nodes are turned off for a period of time, the total area coverage is checked before each turning off of the nodes. This way energy is saved, and coverage is maintained within the desired limits.

The problem of determining the intersection of the fields of view for two sensors was solved mathematically. Each sensor was considered to be a sector of a circle. This way, the problem became one of finding the area of the intersection for two sectors of circles. Using AutoCad [23] we determined that there are 11 possibilities for the intersection of two sectors of a circle. The particular cases were considered to be solved automatically and were considered to belong to the general case. The cases found are presented in Fig. 3.

To illustrate the computation of the intersection area of two sectors of circle, a detailed example is presented next. One of the most often encountered positions for the field of view intersection is presented in Fig. 3e. Fig. 4 shows the detailed view of this type of intersection.

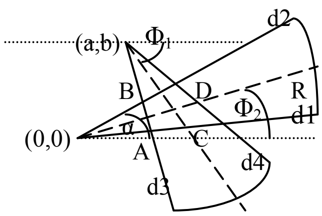

Figure 4. Detailed view for case 3e.

We considered that all sensors are identical. For each sensor we know the angle α, which is the opening angle of the sensors, the angle φ, the angle of the sensor with respect to the axis *x* – which is also the direction of the sensor, R, the radius of the sensor, and the position of each sensor.

The intersection points of the two sensors are computed using the angular coefficient. For example, point A is the intersection of d1 and d3. The equation for d1 is as follows:

$$y = mx, \tag{1}$$

where

$$m = tg(\Phi_2 - \frac{\alpha}{2}). \tag{2}$$

The equation for d3 is:

$$y-b = p(x-a), \tag{3}$$

where

$$p = tg(180-(\Phi_1+ \frac{\alpha}{2})). \tag{4}$$

The intersection point *A* results after solving the equation system formed by the equations d1 and d3. Similarly, the other intersection points were found.

From equations (1) and (3) we calculated *x* and *y* as:

$$x = \frac{pa+b}{m-p} \text{ and } y = m\, \frac{pa+b}{m-b}. \tag{5}$$

The intersection area of the two sectors of circle is in this case:

$$A = \int_{\frac{b-m'a}{m-m'}}^{\frac{b-pa}{m-p}} mx\,dx - \int_{\frac{b-m'a}{m-m'}}^{\frac{m'a-b}{m'}} (b+m'x-m'a)\,dx + \int_{\frac{b-pa}{m-p}}^{\frac{pa-b}{p}} (b+px-pa)\,dx, \tag{6}$$

where

$$m' = tg(\Phi_2 + \frac{\alpha}{2}). \tag{7}$$

Another example of intersection often encountered is the case Fig. 3k. The notation of the sensors intersections is the same as in Fig. 4, bur the positions of the sensors is different. In this case, the area of the intersection is:

$$A = \frac{\alpha^2 R^2}{2} - S, \tag{8}$$

where

$$S = \int_{\frac{b-m'a}{m-m'}}^{R\cos\alpha} [mx-b-m'(x-a)]\,dx + \int_{R\cos\alpha}^{x1} \sqrt{R^2-x^2}\,dx, \tag{9}$$

where

$$\int \sqrt{R^2-x^2}\,dx = \frac{R^2}{2}\arcsin\frac{x}{R} + \frac{x}{2}\sqrt{R^2-x^2} + C \tag{10}$$

and α is considered for the case in which $\Phi_2 - \frac{\alpha}{2} = 0$.

The other cases were computed in a similar way. In addition to the computation of the areas, the algorithm finds all intersecting neighbors of each sensor, calculates the intersection, and turns off the less significant sensors.

B. Network Reconfiguration Strategy

The approach assumes that the energy resource of sensor nodes is limited and irreplaceable. After node deployment in the surveillance area, the number of operating nodes decreases and the functionality of the network gradually reduce as time elapses. The common but complex solution is redeployment of additional nodes. Other solutions attempt to save energy at each node.

We propose here an approach that wakes up redundant nodes in order to replace the node that runs out of energy. It uses the tables that keep neighbor Fields of View overlap set computed in the previous step. If one node detects a low energy level of its battery, it wakes up its neighbor with the higher field overlap. If there is no confirmation before timeout or if a negative response is received then it steps through the overlap table and finds the best neighbor that is still available. A neighbor is unavailable if it is already waked up or if it is also running low on energy.

The main goal of applying this strategy is field coverage preservation. However, the efficiency of the strategy strongly depends on the node redundancy. Estimation is possible if we know that *R* is the number of redundant nodes in a network of size *N*. If we consider $p(N_{tx})$ the probability of a working node

x running out of energy at a moment tx, and if $p(N_{tx})$ is a uniform distribution over all homogenous network nodes, the probability that a node has at least one redundant neighbor to run out of energy at moment tx is estimated as:

$$P(R_{tx}) = P(N_{tx}) * R / N \quad (11).$$

Equation (11) shows a linear dependency between redundancy and the probability of successful replacement of dead nodes.

The algorithm for selecting an optimized subset of cameras to reducing redundancy is summarized next.

```
for(each active node N) {
  for(each active node N' in the set S of
      neighboring nodes) {
    if(FOV overlap between N and N' > 70%)
                    deactivate node N'
    }
}
```

V. Experimental Results

A. Experimentation Platform

To validate our approach we simulated a video-based WSN of variable size between 30 and 300 nodes deployed on a 600*m* x 600*m* surface. Algorithms were implemented as stand-alone Java packages running on an Intel Core-Duo 2MB RAM PC.

The studied topologies were generated using a uniform random distribution provided by the standard Java library class java.util.Random. We considered only homogenous networks. All camera nodes had the same characteristics, video resolution of 160x120 pixels and a view angle of 60 degree. The maximum relevant distance *DMax* of a sensor was estimated using a Trendnet IP-400W wireless surveillance camera, considering an adult person as the smallest target. Consequently, *DMax* was set to 80 m. No obstacles or hard environmental conditions were considered during simulation.

B. Results on Random 30 to 300 nodes networks

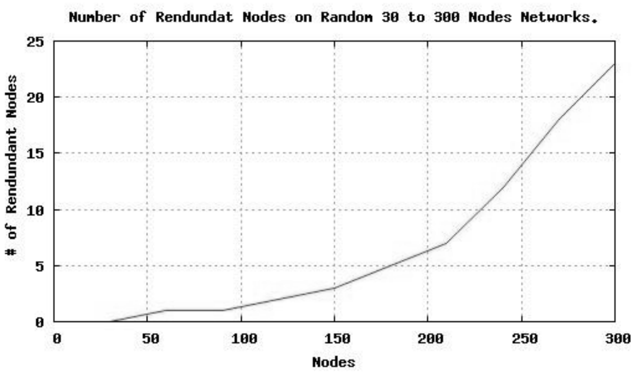

Figure 5. Number of redundant nodes for random networks with 30 to 300 nodes.

Fig. 5 presents the average number of redundant nodes after twenty experiments over a series of ten random networks of size 30 to 300 nodes with an increment of 30 nodes. The redundancy for a 300 nodes network is 23 nodes out of 300 nodes (7.6%).

As depicted in Fig. 6, the surface coverage variance is very low. It is below 2% for a 300 nodes network.

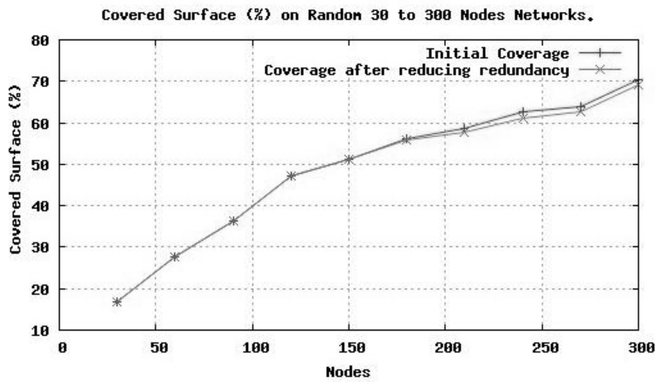

Figure 6. The covered surface variance after reducing redundancy for random networks with 30 to 300 nodes.

Simulation time is presented in Fig. 7. The exponential growing is due to the *N x N* pairs of sensor field of view intersections that must be analyzed.

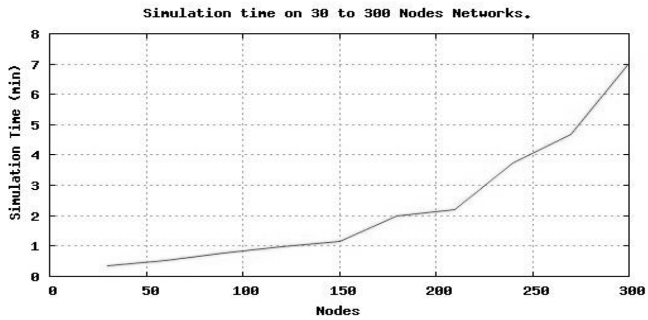

Figure 7. Simulation time for random networks with 30 to 300 nodes.

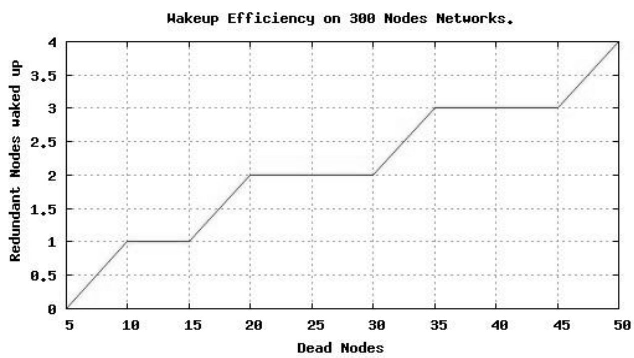

Figure 8. Wakeup efficiency for a network with 300 nodes.

Results for the efficiency of our approach are presented in Fig. 8 and Fig. 9. The first figure shows the number of useful redundant nodes when the number of out-of-power nodes increases from 5 nodes to 50 nodes.

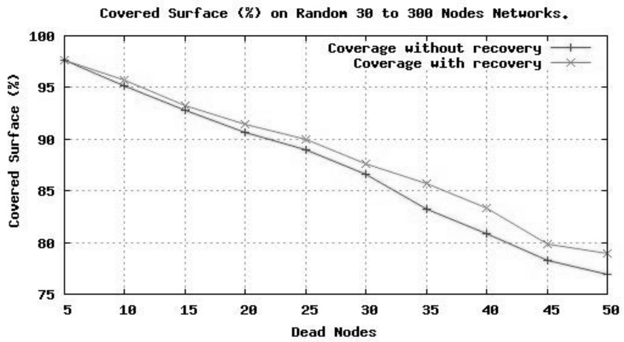

Figure 9. The covered surface variance for a network with 300 nodes with and without redundant nodes recovery.

Fig. 9 expresses the benefit of applying redundant node strategy for preserving the covered surface. Even if the network is less redundant (7.6%), the coverage surface gain is between 2% and 4% but it increases with network size.

VI. Conclusions

Video-based Wireless Sensor Networks applications have a high-energy consumption due to data processing and transmission. This paper proposes an energy efficient approach that prolongs the network lifetime while preserving field coverage. During the deployment phase, redundant nodes are detected and some are put in stand-by. This process keeps certain field coverage. At runtime, each active node evaluates its energy and if it is lower than a preset threshold, a redundant neighbor in stand-by is asked to wake up. The method efficiency is investigated through simulation.

References

[1] I.F. Akyildiz, W. Su, Y. Sankarasubramaniam, and E. Cayirci, "Wireless Sensor Networks: a Survey", *Journal of Computer Networks*, vol. 38, pp. 393–422, 2002.

[2] D. Tao, H. Ma1, and Y. Liu, "Energy-Efficient Cooperative Image Processing in Video Sensor Networks," *PCM 2005, Part II, LNCS 3768*, pp. 572 – 583, 2005.

[3] M. Chen,V. Leung,S. Mao, and Y. Yuan, "Directional geographical routing for real-time video communications in wireless sensor networks," *Computer Communications*, vol. 30(17), pp. 3368-3383, November 2007.

[4] S. Soro and W. B. Heinzelman, "On the Coverage Problem in Video-based Wireless Sensor Networks*", in Proceedings of the 2nd International Conference on Broadband Networks*, vol. 2, pp. 932-939, 2005.

[5] U.M. Erdem and S. Sclaroff, "Optimal Placement of Cameras in Floor plans to Satisfy Task Requirements and Cost Constraints," *in Proceedings of OmniVis2004, the fifth Workshop on Omnidirectional Vision, Camera Networks and Non-classical Cameras,* May 2004

[6] Xin Liu, "Coverage with Connectivity in Wireless Sensor Networks," *in Proceedings of the 3rd International Conference on Broadband Communications, Networks and Systems BROADNETS'2006*, San Jose, USA, pp. 1-8, October 2006.

[7] C. Istin and D. Pescaru, "Deployments Metrics for Video-based Wire less Sensor Networks," *UPT Transactions on Automatic Control and Computer Science, ISSN 1224-600X*, vol. 52(66), no. 4, pp. 163-168, 2007.

[8] B. Chen, K. Jamieson, H. Balakrishnan, and R. Morris, "Span: An Energy-efficient Coordination Algorithm for Topology Maintenance in Ad-hoc Wireless Networks," *in Proceedings of*ACM/IEEE *MobiCom2001*, July 2001.

[9] Y. Xu, J. Heidemann, and D. Estrin, "Adaptive Energy - Conserving Routing for Multihop Ad hoc Networks," *Technical Report 527, USC/ISI*, Oct.2000.

[10] T. Shepard, "A channel Access Scheme for Large Dense Packet Radio Networks", *in Proc of ACM SIGCOMM 1996*, pp. 219-230, 1996

[11] C. Intanagonwiwat, R. Govindan, and D. Estrin, "Directed Diffusion: a Scalable and Robust Communication Paradigm for Sensor Networks," *in Proceedings of the 6th Annual ACM/IEEE MobiCom*, Boston, USA, August 2000

[12] S. Yoon and R. Dutta, and M. L. Sichitiu, "Power Aware Routing Algorithms for Wireless Sensor Networks," *in Proceedings of the Third International Conference on Wireless and Mobile Communications ICWMC '07*, 2007

[13] M. W. Subbarao, "Dynamic Power-conscious Routing for MANETS: an Initial Approach," *in Proceedings of the IEEE Vehicular Technology Conference*, pp. 1232–1237, 1999.

[14] I. Stojmenovic and X. Lin., "Power-aware Localized Routing in Wireless Networks," *IEEE Transactions on Parallel and Distributed Systems*, vol. 12, no. 11, pp. 1122–1133, 2001.

[15] V. Rodoplu and T. H. Meng, "Minimum Energy Mobile Wireless Networks," *IEEE JSAC*, vol. 17, no. 8, pp. 1333–44, Aug. 1999.

[16] W. R. Heinzelman, A. Chandrakasan, and H. Balakrishnan, "Energy-efficient Communication Protocol for Wireless Microsensor Networks," *HICSS*, 2000.

[17] J. Aslam, Q. Li, and D. Rus, "Three Power-aware Routing Algorithms for Sensor Networks," *Wireless Communications and Mobile Computing*, vol. 2, no. 3, pp. 187–208, 2003.

[18] Q. Li, J. Aslam, and D. Rus, "Online Power-aware Routing in Wireless Ad-hoc Networks," *in Proceedings* of ACM/IEEE *MobiCom2001,* pp. 97–107 July 2001.

[19] X. Wang, L. Ding, D.W. Bi, and S. Wang, "Energy-efficient Optimization of Reorganization-Enabled Wireless Sensor Networks," *Sensors Journal,* vol. 7, pp. 1793-1816, 2007

[20] M. Rahimi, D. Estrin, R. Baer, H. Uyeno, and J. Warrior, "Cyclops: image sensing and interpretation in wireless networks," in *Proceedings of the ACM SenSYS 2004*, November 2004.

[21] D. Pescaru, D. Fuiorea, V. Gui, C. Toma, G. Muntean, and A. Doboli, "Image-based Node Localization Algorithm for Wireless Video Sensor Networks," *in Proceedings of IT&T'06 Conference, Ireland*, pp. 139-148, October 2006.

[22] E. Shih, S. Cho, N. Ickes, R. Min, A. Sinha, A. Wang, and A. Chandrakasan, "Physical Layer Driven Protocol and Algorithm Design for Energy-Efficient Wireless Sensor Networks", in *ACM SIGMOBILE Conference on Mobile Computing and Networking, Rome, Italy,* 2001.

[23] ***, "AutoCAD® 2008 Documentation", www.autodesk.com/autocad