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Adaptive Deployment Scheme and Multi-path Routing Protocol for WMSNs

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Abstract

Multi-path routing protocols have many advantages in wireless multimedia sensor networks. To succeed in setting up multiple paths in the wireless multimedia sensor network, the Adaptive Deployment Scheme of sensor Nodes which is based upon multi-path routing protocol (ADSN) is proposed in the paper. ADSN deploys the sensor nodes on the basis of the number of paths, camera nodes' positions and the sink's position etc. Compared to the uniform deployment scheme, ADSN can save 67% sensor nodes when setting up multiple paths. And it can avoid the hotspot area in the vicinity of the sink. Energy Equalization Multi-path Routing protocol (EEMR) can consume the energy of sensor nodes more evenly and extends the network lifetime compared to TPGF.

Keywords: *wireless multimedia sensor networks, multi-path routing, deployment of sensor nodes, network lifetime*

1. Introduction

Wireless Multimedia Sensor Networks (WMSNs) are networks of wirelessly interconnected sensor nodes equipped with mutimedia devices, such as cameras and microphones, and capable to retrieve video and audio streams, still images, and scalar sensor data. WMSNs are the high version of wireless sensor networks [1-3].

WMSNs produce a huge amount of data, and the transmission of these data in a single path cannot satisfy the need of some applications. Multi-path transmission can increase transmission capability, reduce end-to-end delay and balance the node's energy consumption [4, 5]. In order to succeed in setting up multiple paths between camera nodes and the sink, enough many sensor nodes must be deployed in the network. Too few nodes lead to be not able to set up multiple paths, and too many nodes lead to increase the cost and cause the signal inference.

The deployment scheme of sensor nodes which is based upon the number of paths has not been studied in the previous literature. To suceed in setting up multiple paths between camera nodes and the sink, the Adaptive Deployment Scheme of sensor Nodes (ADSN) is proposedin the paper. ADSN deploys the sensor nodes on the basis of several factors such as the number of paths, camera nodes' positions and the sink's position. Compared to the uniform deployment scheme, ADSN can save67% sensor nodes when setting up multiple paths. On the basis of ADSN, the paper proposes Energy Equalization Multi-path Routing protocol (EEMR) which considers the residual energy of sensor nodes can consume the residul energy of sensor nodes more evenly than TPGF. Compared to TPGF, EEMR can extend the lifetime of network.

2. The Proposed Method

GPSR [6] is early geographic routing protocol for wireless networks. GPSR makes greedy forwarding decisions using one-hop neighbours' information. But GPSR is not designed for wireless sensor networks and GPSR have some shortcomings when applying in wireless multimedia sensor network. Because of constraint resources of wireless multimedia sensor networks, energy consumption is considered as the important factor. But GPSR doesn't consider the node' energy consumption and the network lifetime. GPSR chooses the best path

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to transmit the data every time and the nodes in these paths are too frequently used to be alive. These early dead nodes can lead to the partition of the network.

Lei Shu et al. [7-9] proposed Two Phase Geographical Greedy Forwarding (TPGF) for exploring multiple optimized node-disjoint transmission paths.It is based upon geographic position information to build routing paths. It can find a path which meets requirements per execution and can be executed repeatedly to find more node-disjoint routing paths. In greedy forwarding phase, the current node chooses the neighbor node which is the nearest from the sink as the next hop node. The chosen next hop node may be farther than the current node from the sink. The advantage of TPGF is that source node can transmit data to the sink through least hops.

3. Research Method

3.1. Problem Statement

Figure 1 shows the architecture of WMSNs. WMSNs consist of camera nodes, common sensor nodes and the sink. Camera nodes are able to capture, process and transmit images and video. Common sensor nodes can sense scalar data and relay data packets of camera nodes and common sensor nodes. The sink is in charge of collecting the interesting data of camera nodes and common sensor nodes and give these data to the user.

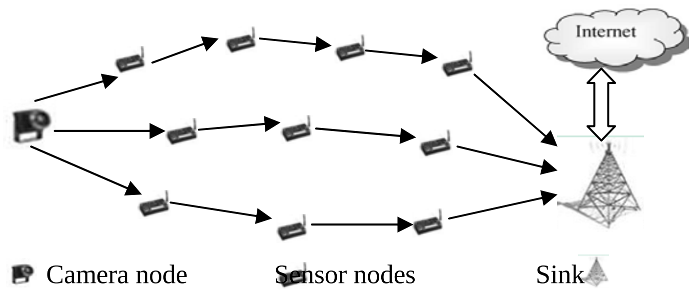


Figure 1. Architecture of Wireless Multimedia Sensor Networks

Image and video that camera nodes capature is considered importantly and the scalar data that common sensor nodes sense is ignored in this paper. So common sensor nodes work as relay nodes. Camera nodes are deployed in fixed position on the basis of the need of monitored object. And camera nodes and common sensor nodes can know their position information using GPS or location algorithm. The coverage of camera nodes is large and their cost is high, so a small number of camera nodes are deployed. Camera nodes are far from the sink. To transmit multimedia data to the sink, a large number of common sensor nodes need be deployed between the camera nodes and the sink. The common sensor nodes serve as relay nodes. Because the price of common sensor nodes is low, the common sensor nodes can be deployed in quality. The multimedia data is forwarded many times to the sink by common sensor nodes. Due to a huge amount of multimedia data, multiple paths need to be set up between camera nodes and the sink. Enough many sensor nodes must be deployed in the network. How many common sensor nodes are needed in the networks and how to deploy these common sensor nodes in the netwoks to set up multiple paths to satisfy the multimedia transmission.

Multimedia information which camera nodes capture contains a large number of data. The generation rate of multimedia information is several tenfold than an actual transmission rate of a common sensor node. Multi-path transmission is needed. A path which is set up in WMSNs is a node-disjoint path. A node-disjoint path is defines as a path which consists of a set of sensor nodes, and none of sensor nodes can be reused for forming another path excluding the source node and the sink [8]. Because sensor nodes in a node-disjoint path use maximum transmission rate to transmit multimedia data, relay nodes can only be used for one path.

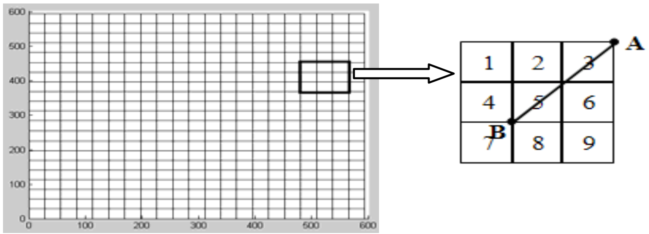
The data generation rate of the camera node is R and the transmission rate of common sensor nodes is TC. To transmit multimedia data which camera nodes have generated to the sink timely, Np disjoint-paths need to be set up between the camera node and the sink. The value of Np is computed by Equation (1).

$$N_p = \lceil R/TC \rceil \quad (1)$$

The transmission radius of camera nodes and common sensor nodes is TR. To set up Np disjoint-node paths between the sink and the camera node, there are at least Np common sensor nodes in the transmission distance TR of the sink and the camera node. The energy consumption model of wireless sensor networks refer to [10].

3.2. Adaptive Deployment Scheme of Sensor Nodes

Previous literatures about multipath routing protocol assume that common sensor nodes are deployed randomly in the network. The random deployment scheme leads to not being set up enough many paths in part area of the network due to having not enough many common sensor nodes in this area. Moreover, sensor nodes in the vicinity of the sink are dead too early due to forwarding too many data packets of other sensor nodes which are far from the sink. The hotspot area will be near the sink. Though there are alive sensor nodes which are far from the sink, there are not alive sensor nodes near the sink which can forward data. The hotspot area will lead to shorten the whole networks.



(a) The whole area (b) The local area

Figure 2. The Divided Grids

Assume that the monitored area is a rectangle and its size is M×N. The rectangle area is divides into many square grids. Figure 2(a) shows the grids that have been divided. The common sensor nodes in adjacent grids must be able to communicate with each other. To guarantee that any common sensor node in the 5th grid can communicate with any common sensor node in the adjacent 8 grids, two common sensor nodes which are farthest in the adjacent grids must be able to communicate with each other. Figure 2(b) shows the two nodes that are farthest in the 3rd grid and the 5th grid. The length of the grid is r and the distance of the line AB is L. The relation of L and r is expressed as Equation (2).

$$L = \sqrt{(2r)^2 + (2r)^2} \quad (2)$$

When the value of L is less than or equal to TR, any common sensor node in adjacent grids can communicate with each other. The relation of TR and r is expressed as Equation (3).

$$r \le \frac{\sqrt{2}}{4} TR \quad (3)$$

According to the requirement of the video surveillance, Nv camera nodes are deployed in monitored area. The coordinate of the camera node is (x_v, y_v) and the coordinate of the sink is (x_s, y_s).

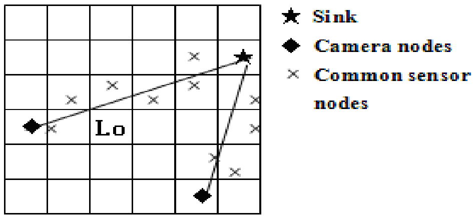


Figure 3. The Deployment Diagram of Common Sensor Nodes

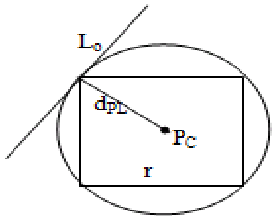


Figure 4. The Distance between the Point P_c and the Line Lo

Figure 3 shows the deployment diagram of common sensor nodes. The line Lo is used to connect the camera node to the sink. The line Lo can be determined by position coordinates of the sink and the camera node. The line equation of Lo is Equation (4).

$$y - y_v = \frac{y_s - y_v}{x_s - x_v}(x - x_v) \tag{4}$$

When the line Lo goes through the grid, common sensor nodes should be deployed in this grid in order to set up optional multiple paths. Figure 4 shows the single square grid. The center of the grid is Pc (x_c, y_c). The distance dPL of the point Pc and the line Lo is computed by Equation (5).

$$d_{PL} = \frac{|(y_s - y_v)x_c - (x_s - x_v)y_c + (x_s - x_v)y_v - (y_s - y_v)x_v|}{\sqrt{(y_s - y_v)^2 + (x_s - x_v)^2}} \tag{5}$$

Figure 4 shows that the line Lo is tangent to the circumscribed circle of the grid. The maximum distance dMAX between the line Lo and the point P_c is expressed as Equation (6).

$$d_{MAX} = \frac{\sqrt{2}}{2} r \tag{6}$$

When the value of d_{PL} is less than the value of d_{MAX}, Ns common sensor nodes are deployed randomly in this grid. The relation of Ns and Np is expressed Equation (7).

$$N_s \geq N_p \tag{7}$$

When Ns equals to Np, enough many common sensor nodes are deployed to guarantee that Np paths will be set up. Because common sensor nodes are easy to fail, the number of common sensor nodes may be added.

On the basis of Equation (3) and Equation (6), Equation (8) is used to check whether the common sensor nodes will be deployed in the current grid.

$$d_{PL} < \frac{1}{4} TR \tag{8}$$

3.3. Choosing the Next-hop Node in EEMR

After the above adaptive deployment scheme of sensor nodes is finished, multiple paths will be set up. TPGF is the traditional multipath routing protocol. But it does not consider the residual energy of sensor nodes when looking for the next hop node. Energy Equalization Multipath Routing protocol (EEMR) which is an improved version of TPGF is proposed to be able to consume sensor nodes' energy more evenly.

Each common sensor node has three states which are available, unavailable and dead. The common sensor node is marked as the dead node when its residual energy is less than specified value. The common sensor node is marked unavailable when it is selected to form a path. In the beginning, all the common sensor nodes are marked available. Each sensor node knows its position information and its 1-hop neighbor node's position and residual energy.

Figure 5 shows the illustration of choosing the next-hop node. The sink is S. The current sensor node is I and the previous node of I is A. The circle I is the communication range of the current sensor node I. The sensor nodes which are in the circle I are called the neighbor nodes of the sensor node I. The IS is the radius of the circle S and the point S is its center. The circle S and the circle I intersect at the point M and N.

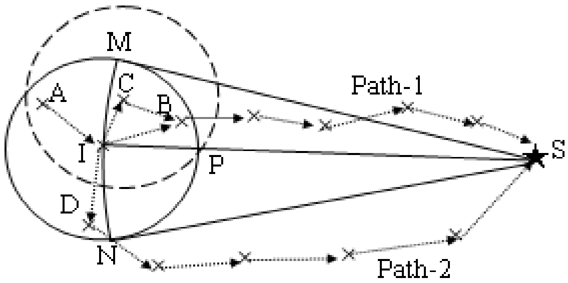


Figure 5. The Illustration of Choosing the Next-hop Node

The current sensor node I chooses the sensor node B as the next-hop node every time using TPGF, because the sensor node B is nearest from the sink in the communication range of the current sensor node I. TPGF does not consider the residual energy of neighbor nodes when choosing the next-hop node. The path-1 which goes through the point B is the path from the sensor node I to the sink.

According to above the routing protocol, the path-2 is not used. To consume the senor nodes' residual energy, more paths should be set up from the source node to the sink. According to the residual energy of neighbor nodes and the distance between the neighbor nodes to the sink, each neighbor node is given a score. The current sensor node chooses the next-hop node according the scores of neighbor nodes. The scores of neighbor nodes are computed Equation (9).

$$f(v_j) = \alpha \bullet \frac{d(v_i,S) - d(v_j,S)}{d(vs_c,S)} + (1-\alpha) \bullet \frac{E_j - E_{ave}}{E_{ini}} \tag{9}$$

v_j is the neighbor node of the current sensor node v_i. $d(v_i,S)$ is the distance from the current sensor node v_i to the sink. $d(v_j,S)$ is the distance from v_j to the sink. $d(vs_c,S)$ is the distance from the camera node to the sink. E_j is the residual energy of v_j. E_{ini} is the initial energy of the sensor node. E_{ave} is the average residual energy of the neighbor nodes.

α is regulatory factor. When the network is in the beginning, the residual energy of sensor nodes is much and the distance factor in Equation (9) should have more effect on the scores of neighbor nodes. When the network runs, the residual energy of sensor nodes is less and the energy factor have more effect on the scores of neighbor nodes. α is computed by Equation (10).

$$\alpha = \frac{E_{ave}}{E_{ini}} \tag{10}$$

3.4. Energy Equalization Multi-path Routing protocol

Camera nodes know the pisitions of the sink and compute Np by Equation (1). Each sensor node knows neighbor nodes' pisitions' information and residual energy by exchanging hello information.EEMR will be executed as the following flow. Camera nodes are deployed in the monitored area and common sensor nodes are deployed by ADSN.

Step 1: the camera node vsi looks for the next hop common senor node. There are m common sensor nodes whose state are available in the communication distance of the camera node vsi. The scores of its neighbor nodes are computed by Equation (9). The camera node choose the next-hop node which score is highest and transmit the explore information to the next-hop sensor node. The selected sensor node is marked unavailable. If there are no available nodes in its communication range, the program is over.

Step 2: the current sensor node vk check whether it can communicate to the sink. If yes, a path will be set up successfully. Step 5 will be executed. If no, step 3 will be executed.

Step 3: the current sensor node vk looks for the next hop node. If there are no neighbor nodes of the current sensor node, step 4 will be executed. If there are the neighbor node in the current sensor node's communication distance, the choice method is similar to the method of the camera node. According to the information of neighbor nodes, the scores of neighbor nodes are computed by Equation (9). The current sensor node chooses the sensor node which score is highest as the next-hop node and transmit the explore information to the next-hop sensor node. The chosen node is marked unavailable and become the current sensor node. Step 2 will be executed.

Step 4: the current sensor node is marked as a blocked node. The explore information is transmitted to the previous-hop sensor node and the previous-hop sensor node becomes the current sensor node. Step 2 will be executed.

Step 5: the sink checks whether the number of paths which are set up equals to Np. If yes, the period of setting up paths is finished, and the sink notifies the camera node to transmit multimedia in built multiple paths. After the transmission is finished, the state of the common senor node is set available. If no, step 1 will be executed.

Other parts of EEMR are the same to TPGF and omitted in the paper.

4. Results and Analysis

Table 1 show the simulation parameter used in the simulation. In the simulation environment, camera nodes are randomly deployed in the rectangular area. The sink is on the upper right.

Table 1. Simulation parameter

Parameter	Value
Network size	$(300\times300)m^2$ $(600\times600)m^2$
Camera nodes	5-20
The sink	1
The position of the sink	(290,290) (590,590)
Np	1-15
TR	80m
Initial energy	5J
The size of image	5000 bytes

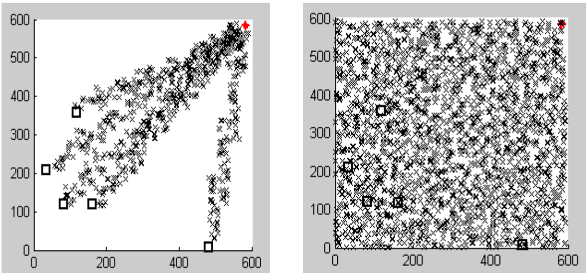
4.1. Simulation of the Deployment Scheme of Sensor Nodes

To compare simulation results, The Uniform Deployment Scheme of sensor nodes (UDSN) is introduced. UDSN is to distribute equal number of common sensor nodes in every grid. The number of paths determines the number of common sensor nodes in every grid. We assume that only one camera node transmits images to the sink through multiple paths at a time. So the number of common sensor nodes does not change in every grid using UDSN when the number of camera nodes increases.

Figure 6(a) and (b) shows the diagram of ADSN and UDSN when 5 camera nodes are randomly deployed in the network and Np equals 5. ADSN needs 730 common sensor nodes and UDSN needs 2205 common sensor nodes. ADSN can save 67% common sensor nodes.

Figure 7 shows the number of common sensor nodes which are needed to set up multiple paths when the number of paths increases. ADSN(Nv) represents that the number of camera nodes is Nv. The number of sensor nodes using ADSN is less than the number of sensor nodes using UDSN.

Moreover, plenty of common sensor nodes are deployed in the area which is near the line between the camera and the sink, which is easy to set up multiple paths. Common sensor nodes using ADSN is converged to the sink. ADSN can be easy to avoid the hotspot area near the sink.



(a) ADSN (b) UDSN

Figure 6. The Diagram of Deployment Scheme of Sensor Nodes

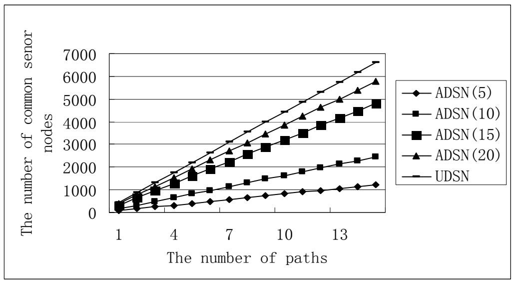
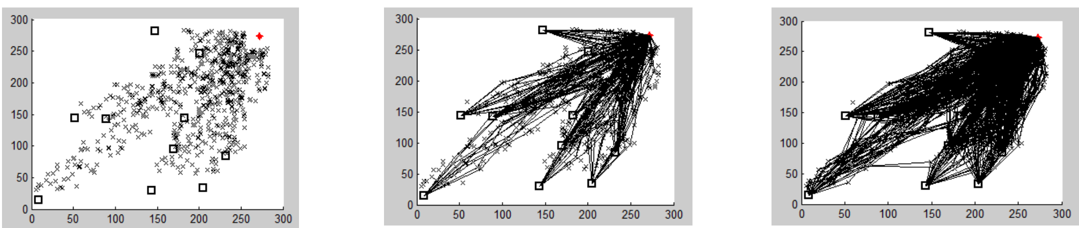


Figure 7. The Number of Common Sensor Nodes

4.2. Simulation of Multi-path Routing Protocol

To demonstrate the simulation result, TPFG and EEMR are realized in the simulation experiment. To show the simulation result clearly, the network size is 300m*300m. 10 camera nodes are randomly deployed and common sensor nodes are deployed by ADSN. Np equals to 4 and Ns equals to 8. The number of common sensor nodes is 696. The energy of camera nodes is not limited and the initial energy of common sensor nodes is 10J. In order to show a simulation result, the following procedure is defined as a round. Each camera node captures 20 images continuously. After images are compressed, the size of each image is 40kB. The images that each camera node captures are transmitted to the sink by 4 different node-disjoint paths.

Figure 8 shows the routing paths after 20 rounds have been executed by using TPGF and EEMR respectively. EEMR produces more paths than TPGF, which means that more nodes are used in building multiple paths.



(a) Node deployment (b) TPGF (c) EEMR

Figure 8. Routing Paths by using TPGF and EEMR

Standard Deviation of Residual Energy (SDRE) can show the distribution of residual energy of common sensor nodes. SDRE is expressed as Equation (11).

$$\text{SDRE} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(E_i - \frac{1}{N}\sum_{i=1}^{N}E_i)^2} \quad (11)$$

Where N is the number of common sensor nodes. Ei is the residual energy of common sensor node i. The value of SDRE is smaller, common sensor nodes consume energy more evenly. Figure 9 shows that EEMR can consume energy more evenly than TPGF. Figure 10 shows the network lifetime by using TPGF and EEMR. EEMR can extend the network lifetime.

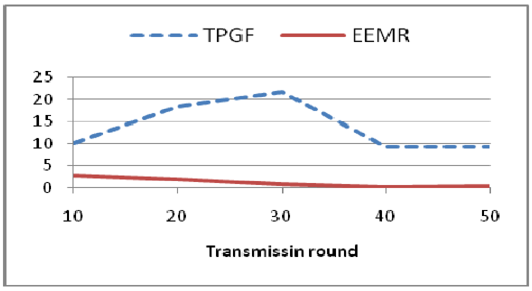


Figure 9. SDRE Distribution Diagram of TPGF and EEMR

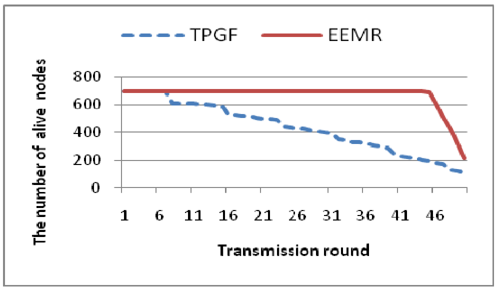


Figure 10. The Network Lifetime of TPGF and EEMR

5. Conclusion

ADSN that is based upon multipath transmission considers the number of paths, camera nodes' positions and the sink's position etc. It can decrease the number of common sensor nodes which are needed to set up multiple paths and avoid the hotspot area problem. EEMR which considers the nodes' residual energy when looking for the next-hop node can more evenly consume nodes' energy and extend the network lifetime. In the future, we will study how to distribute the image compression tasks along the multi-paths.

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