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An Energy Efficient Adaptive Location Aided Flooding Protocol for Wireless Sensor Networks

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Abstract: An energy-efficient flooding mechanism termed Adaptive Location Aided Flooding (ALAF) for wireless sensor networks is proposed in this paper. This protocol uses location information to reduce redundant transmissions, thereby saving energy. The sensor network is divided into non-uniform virtual grids and each sensor node associates itself with a virtual grid based on its location. In areas with dense node deployment smaller sized grids are maintained. Sensor nodes within a virtual grid are classified as either gateway nodes or internal nodes. While gateway nodes are responsible for forwarding the data across virtual grids, internal nodes forward the data within a virtual grid. The proposed approach ALAF, achieves energy savings by reducing the redundant transmissions of the same packet by a node. The performance of ALAF for different grid sizes and different node densities are studied. It is compared with other well-known methods. Thus it can be shown that ALAF saves significant amount of energy when compared to prior methods.

Key words: Adaptive location aided flooding, sensor networks, virtual grids

INTRODUCTION

Recent advances in wireless communications and electronics have enabled the development of low-cost, low-power, multifunctional sensor nodes that are small in size and communicate un-tethered in short distances. These tiny sensor nodes, which consist of sensing, data processing and communicating components, leverage the idea of sensor networks. Sensor networks represent a significant improvement over traditional sensors.

A sensor network is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes need not be engineered or predetermined. This allows random deployment in inaccessible terrains or disaster relief operations. On the other hand, this also means that sensor network protocols and algorithms must possess self-organizing capabilities. Another unique feature of sensor networks is the cooperative effort of sensor nodes. Sensor nodes are fitted with an onboard processor. Instead of sending the raw data to the nodes responsible for the fusion, they use their processing abilities to locally carry out simple computations and transmit only the required and partially processed data.

There are a wide range of applications for sensor networks. Some of the application areas are Military Application, Environment Application, Health Application, Home Application and other commercial applications like Environmental control in office buildings, Interactive museums, Detecting and monitoring car thefts, Managing inventory control, Vehicle tracking and detection.

Conventional protocols use classical flooding for disseminating data in a sensor network. Flooding is also used as a preprocessing step in many routing protocols in networks for disseminating route discovery requests. Information dissemination protocols are used in networks for distributing the link state information. Routers in the Internet periodically use flooding to update link state information at other nodes.

Despite many of its uses, flooding suffers from disadvantages such as the broadcast storm problem. There are situations when duplicated messages are sent to the same node and also if two nodes share the same observing region, neighbor nodes receive duplicated messages. The flooding protocol does not take into account of the available energy resources. Sensor nodes are typically characterized by small form-factor, limited battery power and a small amount of memory. So there is a need for an energy-efficient flooding mechanism for information dissemination in distributed sensor networks.

RELATED WORK

In[1], flooding protocol is presented in which each node receiving a data or management packet repeats it by

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broadcasting, unless a maximum number of hops for the packet is reached or the destination of the packet is the node itself. Flooding is a reactive technique and it does not require costly topology maintenance and complex route discovery algorithms. However, it has several deficiencies such as Implosion, Overlap and Resource blindness.

A derivation of flooding is gossiping[1] in which nodes do not broadcast but send the incoming packets to a randomly selected neighbor. A sensor node randomly selects one of its neighbors to send the data. Once the neighbor node receives the data, it selects randomly another sensor node. Although this approach avoids the implosion problem by just having one copy of a message at any node, it takes long time to propagate the message to all sensor nodes.

A family of adaptive protocols called SPIN[1] is designed to address the deficiencies of classic flooding by negotiation and resource adaptation. The SPIN family of protocols are designed based on two basic ideas: sensor nodes operate more efficiently and conserve energy by sending data that describe the sensor data instead of sending the whole data, e.g., image and sensor nodes must monitor the changes in their energy resources. SPIN has three types of messages, i.e., ADV, REQ and DATA. Before sending a DATA message, the sensor broadcasts an ADV message containing a descriptor, i.e., meta-data, of the DATA. If a neighbor is interested in the data, it sends a REQ message for the DATA and DATA is sent to this neighbor sensor node. The neighbor sensor node then repeats this process. As a result, the sensor nodes in the entire sensor network, which are interested in the data, will get a copy. SPIN is based on data-centric routing.

A flooding algorithm based on neighborhood knowledge (self-pruning), is H. Lim[2]. Each node obtains 1-hop neighbor information through periodic Hello packets. Each node includes a list of its one-hop neighbors in the header of each broadcast packet. A node receiving a broadcast packet compares its neighbor list to that of the sender's neighbor list. If the receiving node cannot reach any additional nodes, it does not broadcast the packet. The scalable broadcast algorithm W. Peng[3] uses 2-hop neighborhood information to limit the number of retransmissions. A node that receives a broadcast packet determines the 1-hop neighbors that need to rebroadcast the packet. A similar approach is taken in the dominant pruning method. This approach uses the header trail of the nodes recently visited by the packet to limit the number of broadcasts. It limits the length of the header trail by using a fixed hop count.

Modified flooding[4] uses node ids to improve the energy efficiency of information dissemination in wireless sensor networks. Each packet sent using modified flooding includes a special field in the packet header called the Node List. The Node List contains the ids of all the nodes that already have the packet. If the network is assumed to be loss-less, the packet header informs the receiver nodes that all the nodes in the Node List already have the packet, hence forwarding the packet to those nodes is unnecessary. Figure 3 and Table 1 shows how the redundant transmissions in flooding can be reduced using modified flooding.

In LAF[4], the sensor network is divided into virtual grids and each sensor node associates itself with a virtual grid based on its location. The nodes send a packet that includes a special field in the packet header called the node list. The node list contains the ids of all the nodes that already have the packet. The packet header informs the receiver nodes that all the nodes in the node list already have the packet, thus avoids broadcasting if all its neighbors have received. In the above mechanism, the packet size increases thereby reducing the energy saving potential of the above scheme, so the node list in the packet is stripped off hypothetically. Thus, the packet becomes shorter as it moves across the virtual grids and increases in size as it moves within a virtual grid.

The drawback in this scheme is that the sensor field is divided into virtual grids of uniform size irrespective of density of the node deployment. When packets circulate over grids with dense node deployment, the node list in the packet increases in size since there is no stripping off within the grid. This consumes a lot of energy.

A localization scheme is used when ALAF is implemented on physical hardware. A range-free localization scheme using mobile anchor points through which the sensor nodes are able to compute their locations is Kuo-Feng Ssu[5].

S-MAC[6] uses a few novel techniques to reduce energy consumption and support self-configuration. It enables low-duty-cycle operation in a multi-hop network. Nodes form *virtual clusters* based on common sleep schedules to reduce control overhead and enable traffic-adaptive wake-up. S-MAC uses in-channel signaling to avoid overhearing unnecessary traffic. Finally, S-MAC applies message passing to reduce contention latency for applications that require in-network data processing.

ADAPTIVE LOCATION AIDED FLOODING

Classical flooding: The flooding is initiated by a node in the sensor field. The source node creates a packet with its id and sequence number and broadcasts the packet to its neighbors. Each node on receiving the packet checks to see whether the packet's sequence number is already in its received list of sequence numbers. If so, drops the

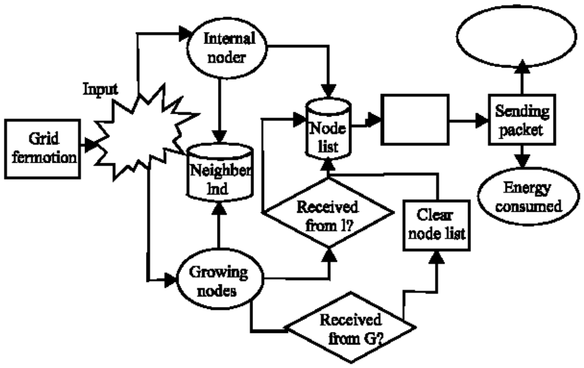


Fig. 1: Location aided flooding

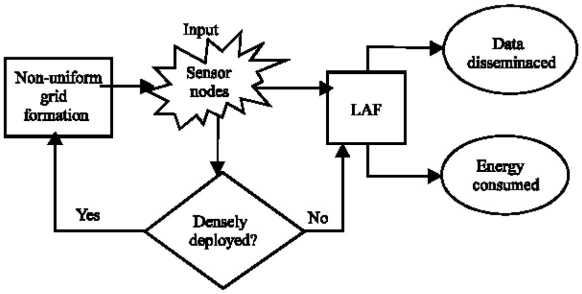


Fig. 2: Adaptive LAF

Table 1: Performance statistics for different flooding protocols

Performance statistics	CF	LAF	ALAF
Total energy consumed (joules)	0.057466	0.054566	0.052611
Average energy consumed (joules)	0.001149	0.001091	0.001052
Sent packets	50	42	42
Received packets	192	181	178

packet. Otherwise, stores the sequence number of the packet it receives and broadcasts it to all its neighbors. Thus in Classical Flooding(CF) each node broadcasts the packet only once.

Location aided flooding: LAF divides the monitored area (sensor field) into "virtual grids." Each node associates itself with a virtual grid depending on its physical location. Sensor nodes within a virtual grid are classified as either gateway nodes or internal nodes. While gateway nodes are responsible for forwarding the data across virtual grids, internal nodes forward the data within a virtual grid. Each node maintains a neighbor list. It achieves energy savings by reducing the redundant transmissions of the same packet by a node. The block diagram Fig. 1 illustrates the LAF protocol.

The header format of the packets used in LAF consists of the source id as well as the sequence number of the packet, the list of the nodes that have already

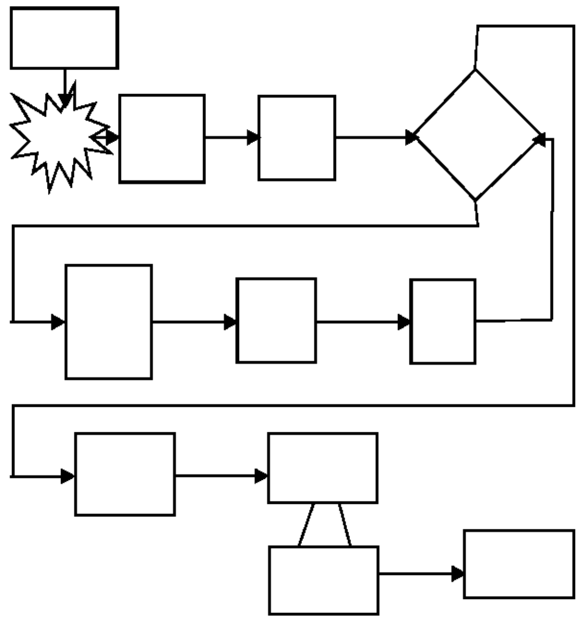


Fig. 3: Grid formation and node classification

received the packet, the id of the grid in which the sender of the packet is currently in and node type. When a node receives a packet, based on the sender's and the receiver's node type, the node list in the packet is modified and either flooded or dropped.

Adaptive LAF: The concept of using non-uniform virtual grids is integrated into location aided flooding in Fig. 2. The grids with dense deployment are further divided into grids. Thus some grids in the sensor field are smaller in size. The node list is frequently stripped off avoiding excessive increase in its size. Consequently energy is also saved.

Grid formation and node classification: Based on the location of the nodes, the sensor field is divided into virtual grids of uniform size. If the number of nodes in a grid exceeds a certain threshold, then the grid is further split into grids of smaller dimensions. Each node associates itself with a virtual grid and are classified as either gateway node or internal node. This scenario is represented in the block diagram given in Fig. 3.

The algorithm for grid formation and node classification is given below:

1. Divide the sensor field into grids based on topography and grid size.
2. For each node,

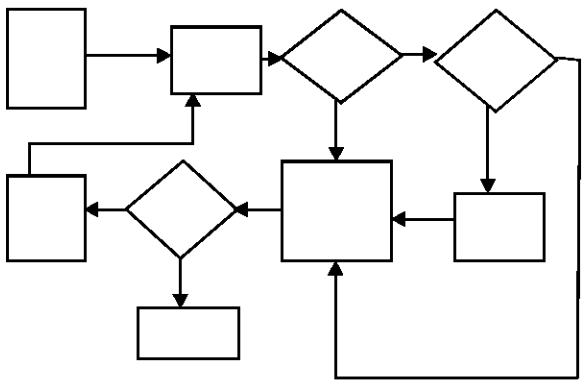


Fig. 4: Data dissemination

- Based on its location in one of the grids formed, set the grid id and maintain the node count in each grid.
- If the node count of the grid exceeds threshold value,
- Get the dimensions of the grid and the new grid size.
- Split the grid based on the input parameters.
- Maintain the count of number of grids formed.
- Set new grid id for the node based on its location in one of the new grids formed.
- Identify the neighbors and store in the neighbor list.
- Classify the node
- If all of its neighbors belong to the same grid as that of the node, then set its node type as internal.
- If any of its neighbors belong to a different grid than that of the node, then set its node type as gateway.

Data dissemination: A source node starting the ALAF broadcasts the packet to all its neighbors. The receiving node does further broadcasts in one of the following ways:

When a gateway node receives a packet from within its virtual grid, it checks to see if any of its neighbors within the same virtual grid have not yet received the packet. This is done by comparing the node list of the packet with the neighbor list of the node. If such nodes exist, then the gateway node appends the ids of those nodes to the node list of the packet and forwards it to the neighbor nodes that still have not received the message. When a gateway node receives a packet from another gateway node, it strips the packet of its node list and adds its own id and all its neighbors' ids and forwards the packet to all its neighbors. Thus, the packet becomes shorter as it moves across the virtual grids and increases in size as it moves within a virtual grid.

When an internal node receives a packet, it modifies the node list of the packet. It includes the ids of all its neighbors in the node list and forwards it to its neighbors message. Data dissemination in the network takes place as given in Fig. 4.

The algorithm for data dissemination is given below:

- The source node creates a packet with its id, sequence number, node list, grid id, node type, node list length. The node list contains its id and the ids of all its neighbors.
- The source node broadcasts the packet to its neighbors.
- The receiving node checks to see whether the packet's sequence number is already in its received list of sequence numbers.
- If so, it drops the packet.
- Else, it stores the sequence number of the packet it receives and sets its id, grid id, node type in the packet.
- If it is an internal node, it compares its neighbor list with the node list in the packet.
- If there are nodes in the neighbor list not present in the node list, it adds those nodes to the node list and broadcasts the packet to its neighbors.
- Else, it drops the packet.
- If it is a gateway node, it checks the node type in the received packet.
- If it has received from an internal node, it compares its neighbor list with the node list in the packet.
- If there are nodes in the neighbor list not present in the node list, it adds those nodes to the node list and broadcasts the packet to its neighbors.
- Else, it drops the packet.
- If it has received from a gateway node, it checks the grid id in the received packet.
- If it has received from a node in the same grid, it compares its neighbor list with the node list in the packet.
- If there are nodes in the neighbor list not present in the node list, it adds those nodes to the node list and broadcasts the packet to its neighbors.
- Else, it drops the packet.
- If it has received from a node in a different grid, it strips off the node list, adds all its neighbors to the node list and broadcasts the packet.

RESULTS AND DISCUSSION

We have developed a simulator in NS2 to evaluate the performance of ALAF and compare it with alternative data dissemination algorithms. We found that ALAF

Fig. 5: Non uniform grid formation

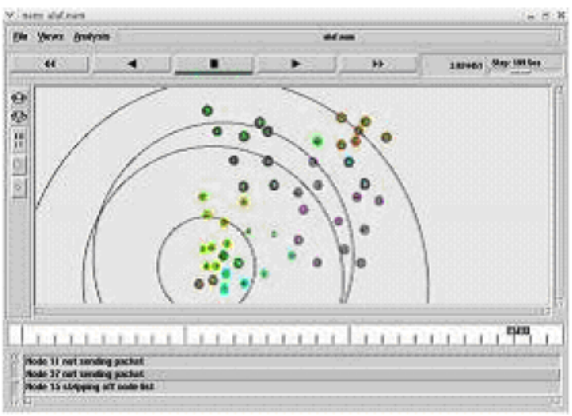


Fig. 6: Dropping packets during data dissemenation

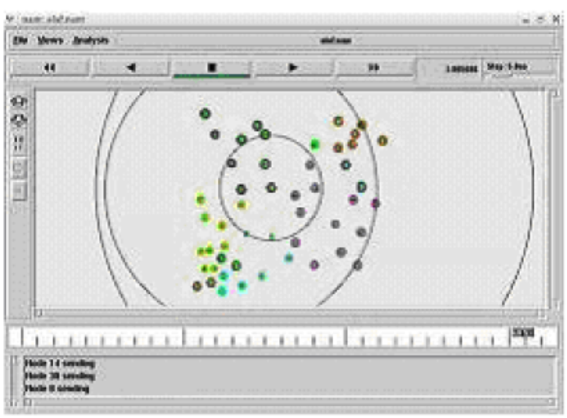


Fig. 7: Data Dissemenation within same grid

protocol achieves higher energy savings compared to both classical flooding and LAF and pruning-based methods while disseminating the data with comparable delay. We also found that the nodes with a higher degree (i.e., nodes with more one-hop neighbors) disseminate more data per unit energy in both LAF and modified flooding compared to classical flooding. Thus, dense sensor networks are likely to benefit more from using the ALAF protocol for data dissemination in terms of energy savings.

Initially a set of 50 nodes are deployed in a 200x200m sensor field using the location information given in the scenario file. The sensor field is divided into four uniform sized grids and each node associates itself with a grid. The nodes are assigned the grid ids 0, 1, 2 and 3, depending on their association. The nodes are further classified as either gateway nodes or internal nodes.

The uniformly divided sensor field is checked for dense deployments and divided into smaller sized grids Fig. 5.

In the deployment given below, grid 1 is densely deployed. So it is further divided into four grids 4, 5, 6 and 7. Also grid 3 is divided into four grids 8, 9, 10 and 11. Now it is seen that grid 5 is still densely deployed and so a second level of splitting is applied giving rise to four grids 12, 13, 14 and

Node 0 initiates flooding as shown in Fig 14. Node 0 fills the node list in a packet with the ids of its neighbor and broadcasts the packet to all its neighbors. Node 41 being a neighbor of node 0 receives the packet. Since nodes 0 and 41 are gateway nodes in different grids, node 41 strips off the node list in the received packet and fills up with the ids of its neighbor and broadcasts the packet to all its neighbors. Node 11 receives the packet from node 17 in the same grid. Since all of its neighbors have already received the packet, node 11 drops the packet without further broadcasts. The same is true with node 37 receiving the packet from node 49. Node 37 sees that all of its neighbors already received the packet and drops the packet without further broadcasts. The scenario is depicted in Fig. 6.

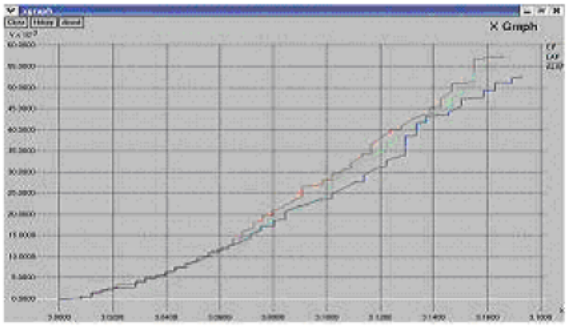
Node 15 receives the packet sent by node 6. Since nodes 15 and 6 are gateway nodes in different grids, node 15 strips off the node list in the received packet and fills up with the ids of its neighbor and broadcasts the packet to all its neighbors.

Node 21 on receiving the packet from node 10, strips off the node list, adds its neighbors to the node list and broadcasts the packet as shown in Fig. 7.

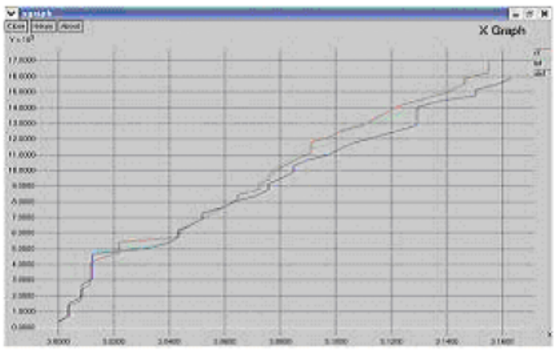
Node 30, an internal node receives the packet sent by the gateway node 21. Since not all of its neighbors have already received the packet, node 30 performs further broadcast.

Node 8, a gateway node receives the packet sent by the gateway node 21 within the same grid. Since not all of its neighbors have already received the packet, node 8 broadcasts the packet.

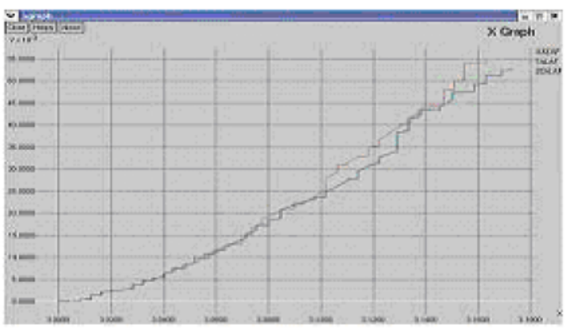
Performance analysis: The efficiency of ALAF compared to the other versions of flooding protocol is brought out



Graph 1: Data dissemination with time



Graph 2: Energy consumption with time



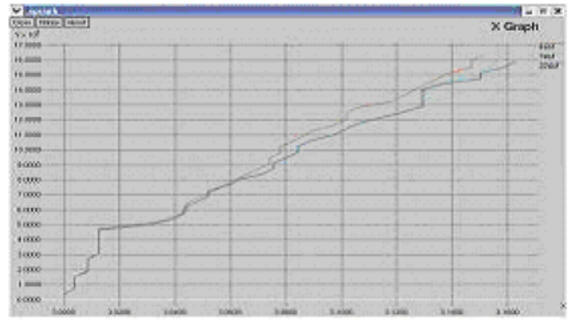
Graph 3: Data disseminated with time

using graphs. Also the graphs help in showing the variations in the performance of ALAF for different thresholds for the node count in grids.

CF, LAF AND ALAF: Each of these flooding schemes is run and a trace of events at each node is stored in a trace file.

The time and packet size fields in the three trace files are retrieved into three separate dat files. A graph is drawn with time along x-axis and the bytes transferred at that time along y-axis shown in Graph 1.

The time and energy fields in the three trace files are retrieved into three separate dat files. A graph is drawn with time along x-axis and energy consumed as a whole at



Graph 4: Energy consumption with time

Table 2: Thresold and number of grids formed

Threshold	No. of grids
5	22
11	7
19	4

Table 3: Performance statistics of ALAF for different thresholds

Performance statistics	5	11	19
Total energy consumed (joules)	0.052929	0.052611	0.052853
Average energy consumed (joules)	0.001059	0.001052	0.001057
Sent packets	43	42	42
Received packets	182	178	178

that time along y-axis shown in Graph 2.

ALAF WITH 4, 7 AND 22 GRIDS:

The Adaptive Location Aided Flooding is run with different thresholds. As a result different number of grids are formed. This is shown in Table 3.

Graphs for data dissemination(Graph 3) and energy consumption(Graph 4) are shown.

4, 7 and 22 grids

4, 7 and 22 grids

CONCLUSION

In this study, a new energy-efficient flooding scheme, termed Adaptive Location Aided Flooding, is presented for data dissemination in wireless sensor networks. The proposed approach uses the concept of uniform and non-uniform virtual grids to partition the sensor nodes into groups of gateway nodes and internal nodes. It exploits the location information available to sensor nodes to prolong the lifetime of sensor network by reducing the redundant transmissions that are inherent in flooding.

Although, a loss-less network is assumed, ALAF protocol can be adapted to lossy networks. A node can use the knowledge about the quality of a link to its neighbor and rebroadcast the packet multiple times. It is important to develop techniques that can dynamically reconfigure the virtual grid in a distributed manner after node failures, wearout and battery depletion. Finally, the energy savings need to be evaluated on physical hardware to demonstrate the usefulness of ALAF.

REFERENCES

1. Akyildiz, I., W. Su, Y. Sankarasubramaniam and E. Cayirci, 2002. A survey on Sensor Networks. IEEE Communications Magazine, 40: 102-114.
2. Lim, H. and C. Kim, 2000. Multicast Tree Construction and Flooding in Wireless Ad Hoc Networks. Proc. ACM Modeling, Analysis and Simulation of Wireless and Mobile Systems, pp: 61-68.
3. Peng, W. and X. Lu, 2000. On the Reduction of Broadcast Redundancy in Mobile Ad Hoc Networks. Proc. ACM Int'l Symp. Mobile and Ad Hoc Networking and Computing, pp: 129-130.
4. Harshavardhan Sabbineni and Krishnendu Chakrabarty, 2005. Location-Aided Flooding: An Energy-Efficient Data Dissemination Protocol for Wireless Sensor Networks. IEEE Transactions on Computers, 54: 36-46.
5. Kuo-Feng Ssu, Chia-Ho Ou and Hewijin Christine Jiau, 2005. Localization With Mobile Anchor Points in Wireless Sensor Networks. IEEE transactions on Vehicular Tech., 54: 1187-1197.
6. Wei Ye, John Heidemann, Deborah Estrin, 2004. Medium Access Control With Coordinated Adaptive Sleeping for Wireless Sensor Networks. IEEE/ACM Transactions on Networking, 12: 493-506.