Energy Efficient Geocast Protocol for Sensor Networks*

YOUNG-CHUL SHIM
Department of Computer Engineering
Hongik University
72-1 Sangsudong, Mapogu, Seoul
REPUBLIC OF KOREA
http://dcnl.cs.hongik.ac.kr

Abstract: - Geocast sends packets to all sensor nodes within a specified geographical region in order to gather data from sensor nodes in that region and is an important mechanism in sensor networks. In this paper we propose a new geocast protocol. The proposed protocol builds a multicast tree connecting geocast nodes using an energy efficient broadcasting technique without making any restrictions on the shape of the geocast region. The proposed protocol reduces the energy consumption during the phase of sending commands to the sensor nodes in a geocast region and also facilitates in-network data aggregation and, therefore, saves energy during the phase of reporting sensor data.

Key-Words: - Sensor Network, Geographic Routing, Multicast, Energy-Awareness

1 Introduction

Sensor networks have been used for a wide range of applications including environment monitoring, traffic surveillance, military sensing and information gathering. Their main purposes are to monitor an area, including detecting, identifying, localizing, and tracking one or more objects of interest. A sensor network consists of one or multiple data center called a sink node and many low-cost and low-powered sensor devices, called sensor nodes. Each sensor node has the ability of sensing data, processing data, and communicating with others via radio transceivers. The sink node, equipped with a database system, sends queries or control commands to sensor nodes and collects information from sensors. The communication between the sink and sensor nodes relies on the relay by intermediate sensor nodes[1].

Because sensor nodes are microelectronic devices, they can only be equipped with a limited power source. Therefore, energy conservation becomes the most important issue when developing routing protocols for sensor networks. Techniques such as in-network data aggregation are needed to reduce energy consumption in sensor nodes.

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In sensor networks a group of sensor nodes in a certain geographic region may cooperate to monitor an object within that region. So multicast to all the sensor nodes in that region becomes an essential mechanism. Geocast, a variant of conventional multicast, sends packets to all the nodes within a specified geographical region. To determine the geocast group membership, each node is required to know its own physical location, i.e., its geographic coordinates, which may be obtained using a system such as the Global Positioning System (GPS)[2].

In this paper we propose a new geocast protocol in sensor networks. We do not make any restrictions on the shape of the geocast region. The proposed protocol reduces the energy consumption during the phase of sending commands from the sink node to the sensor nodes in a geocast region and also facilitates in-network data aggregation and, therefore, saves energy during the phase of reporting sensor data to the sink node..

The rest of the paper is organized as follows. Section 2 surveys the related work. Section 3 describes the proposed protocol and is followed by discussions and conclusions in sections 4 and 5.

2 Related Works

In this section we first survey related works on geocast then we describe works on efficient broadcasting techniques.

2.1 Geocast

In general geocast protocols consist of two phases. In the first phase a packet is delivered from the source to one or more nodes in the geocast region. Then the packet is broadcast to all the nodes in the geocast region. Although a geocast protocol consists of two phases, most of proposed geocast protocols for MANETs focus on the protocol for the first phase and assume the use of flooding for the second phase. Yao et al classified geocast protocols into three categories: flooding-based protocols, routing-based protocols, and cluster-based protocols[2].

Flooding-based protocols use flooding or a variant of flooding to forward geocast packets from the sink to the geocast region[2]. Protocols in this category include Location-Based Multicast(LBM)[3] and Voronoi Diagram based Geocasting(VDG)[4]. LBM is essentially identical to flooding packets, with the modification that a node determines whether to forward a geocast packet further via one of two schemes. In LBM scheme 1, when a node receives a geocast packet, it forwards the packet to its neighbors if it is within a forwarding zone: otherwise, it discards the packet. A forwarding zone can be the smallest rectangle that covers both the source and the geocast region or the smallest cone covering the geocast region with the sink as the vertex. In LBM scheme 2, whether a geocast packet should be forwarded is based on the position of the sender node at the transmission of the packet and the position of the geocast region. That is, for some parameter δ, a node B forwards a geocast packet from a node A, if the node B is at least δ closer to the center of the geocast region than the node A. The forwarding zone defined in LBM may be a partitioned network between the sink and the geocast region, although there exists a path between the source and the destination. To solve this problem, in VDG, the definition of the forwarding zone of LBM has been modified. The neighbors of the node A that are located within the forwarding zone in VDG are exactly those neighbors that are closest in the direction of the destination.

Routing-based protocols create routes from the source to the geocast region via control packets[2]. Protocols in this category include the GeoTORA[5] and Geocast Adaptive Mesh Environment for Routing(GAMER)[6] and Mesh-based Geocast Routing protocol(MGR)[7]. In GeoTORA, a source node essentially performs an anycast to any node in the geocast region via TORA which is a unicast routing protocol for MANETs. When a node in the geocast region receives a packet, it floods the packet to the geocast region. GAMER provides a mesh of paths between the sink and the geocast region. The mesh is created by flooding JOIN-DEMAND(JD) packets within a forwarding zone. Once a node in the geocast region receives a non-duplicate JD packet, it generates a JOIN-TABLE(JT) packet and unicasts it back to the source following the reverse route taken by the JD packet. All of the nodes in the reverse route become parts of the mesh. Data packets generated by the source are forwarded by the mesh members within the mesh and flooded within the geocast region. MGR is similar to GAMER.

Cluster-based protocols geographically partition a MANET into several disjoint and equally sized cellular regions and select a cluster head in each region for executing information exchange[2]. Protocols in this category include GeoGRID[8]. GeoGRID partitions the geographic area of the MANET into two-dimensional logical grids. Each grid is a square of size $d*d$. A gateway node is elected within each grid. The forwarding zone is defined by the location of the source and the geocast region and only gateway nodes in forwarding zone transmit packets. There are two schemes on how to send geocast packets: Flooding-Based GeoGRID and Ticket-Based GeoGRID

Geographic and Energy Aware Routing(GEAR) algorithm is a geocast protocol for sensor networks[9]. It uses energy aware neighbor selection to route a packet towards the geocast region and Recursive Geographic Forwarding algorithm to disseminate the packet inside the geocast region. When a node receives a packet, among its neighbors GEAR picks the next hop minimizing the cost which is the combination of the distance to the geocast region and the consumed energy. GEAR also includes a mechanism to route around a hole.

2.2 Efficient Broadcasting

Techniques for network wide broadcasting in MANETs can be applied to broadcasting packets in a geocast region in sensor networks. In this subsection we first survey broadcasting techniques in MANETs and then introduce some protocols developed for broadcasting packets in a geocast region in sensor networks.

Broadcast techniques in MANETs are classified into four categories: simple flooding, probability based methods, area based methods, and neighbor knowledge methods[10].

The algorithm for Simple Flooding starts with a source node broadcasting a packet to all neighbors. Each of those neighbors in turn rebroadcasts the packet exactly once and this continues until all reachable network nodes have received the packet[10].

Probability based methods use some basic understanding of the network topology to assign a probability to a node to rebroadcast. There are the probabilistic scheme and counter-based scheme in this category[11]. The probabilistic scheme is similar to flooding, except that nodes only rebroadcast with a predetermined probability. In the counter-based scheme, upon reception of a previously unseen packet, the node initiates a counter with a value of one and sets a RAD(which is randomly chosen between 0 and *Tmax* seconds). During the RAD, the counter is incremented by one for each redundant packet received. If the counter is less than a threshold value when the RAD expires, the packet is rebroadcast. Otherwise, it is simply dropped[10].

Area based methods assume nodes have common transmission distances: a node will rebroadcast only if the rebroadcast will reach sufficient additional coverage area. There are the distance-based scheme and the location-based scheme in this category[11]. In the distance-based scheme, a node compares the distance between itself and each neighbor node that has previously rebroadcast a given packet. Upon reception of a previously unseen packet, a RAD is initiated and redundant packets are cached. When the RAD expires, all source node locations are examined to see if any node is closer than a threshold distance value. If true, the node doesn't rebroadcast. In the location-based scheme, each node must have means to determine its own location, e.g., a GPS. Whenever a node originates or rebroadcasts a packet, it adds its own location to the header of the packet. When a node initially receives a packet, it notes the location of the sender and calculates the additional coverage area obtainable were it to rebroadcast. If the additional area is less than a threshold value, the node will not rebroadcast, and all future receptions of the same packet will be ignored. Otherwise, the node assigns a RAD before delivery. If the node receives a redundant packet during the RAD, it recalculates the additional coverage area and compares that value to the threshold[10].

Neighbor knowledge methods maintain state on their neighborhood, which is used in the decision to rebroadcast. There are Flooding with Self Pruning[12], Scalable Broadcast Algorithm(SBA)[13], Dominant Pruning[12], Multipoint Relaying[14], Ad Hoc Broadcast Protocol(AHBP)[15], Connected Dominating Set(CDC)-Based Broadcast Algorithm[16], and Lightweight and Efficient Network-Wide Broadcast(LENWB)[17] in this category. Among them, we describe first two protocols. The Flooding with Self Pruning protocol requires that each node have knowledge of its 1-hop neighbors, which is obtained via periodic “Hello” packets. A node includes its list of known neighbors in the header of each broadcast packet. A node receiving a broadcast packet compared its neighbor list to the sender's neighbor list. If the receiving node would not reach any additional nodes, it refrains from rebroadcasting: otherwise the node rebroadcasts the packet. SBA requires that all nodes have knowledge of their neighbors within a two hop radius. This neighbor knowledge coupled with the identity of the node from which a packet is received allows a receiving node to determine if it would reach additional nodes by rebroadcasting. 2-hop neighbor knowledge is achievable via periodic “Hello” packets; each “Hello” packet contains the node's identifier and the list of known neighbors. After a node receives a “Hello” packet from all its neighbors, it has 2-hop topology information centered at itself[10].

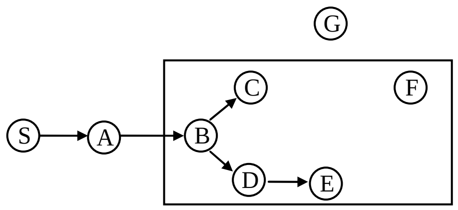
Some techniques have been proposed to efficiently broadcast packets to a geocast region in sensor networks. Single branch Multicst tree(SAM) and Cone-based Forwarding Area Multicast tree(CoFAM) build a multicast tree among nodes in the geocast region and use some heuristics for building the multicast tree[18]. GEAR uses a Recursive Geographic Forwarding algorithm to disseminate the packet inside the geocast region R. Suppose the geocast region R is the big rectangle and a node N receives a packet P for region R, and finds itself inside R. In this case, N divides the region R into 4 sub-regions, each of which is a smaller rectangle and 1/4 of R, and creates four new copies of P bound to 4 sub-regions of region R. Repeat this recursive splitting and forwarding procedure until the stop condition of recursive splitting and forwarding is satisfied. The recursive splitting terminates if the current node is the only one inside this sub-region[9].

These broadcasting techniques can be applied when developing geocast protocols but it is not desirable to make any assumptions on the shape of the geocast region.

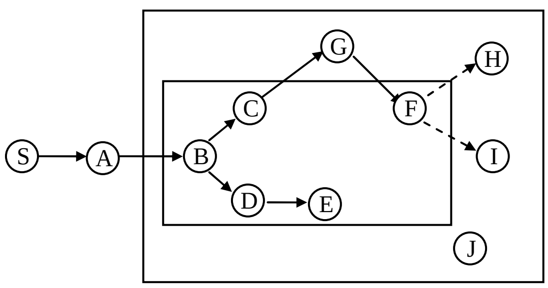
3 Protocol Description

In this section we describe the proposed geocast protocol in sensor networks. The protocol reduces energy consumption and facilitates the in-network data aggregation.

The geocast command issued from the sink is routed to a first sensor node, which is called an access point (AP) node, in the geocast region using the GEAR protocol described in the precious section. Then using the AP node as a root, a multicast tree is built among sensor nodes either in the geocast region only or in the forwarding region. Figure 1 (a) shows a multicast tree built among nodes in the geocast region which is depicted as a rectangle. The node F cannot join the tree because none of other nodes in the geocast region can reach F in 1 hop. The outer rectangle in Figure 1 (b) is a forwarding region. A forwarding zone for a geocast region is bigger than the geocast region and includes it. If we use the node G which is not in the geocast region but in the forwarding region, the node F can be connected to the tree. If we use nodes which are not in a geocast region but in a forwarding region when we build a tree, the probability that a geocast region node is not included in the tree due to the hole problem is reduced. In this subsection we describe two protocols for building a multicast tree: one using nodes in a geocast region and the other using nodes in



(a) Tree using geocast region nodes only



(b) Tree using forwarding region nodes

Fig.1 Multicast Trees for Geocast

a forwarding region. The decision which protocol to use is made by the sink node and the different command is sent from the sink node.

In this paper we assume that after a sensor network is deployed, a new sensor node cannot be added but a sensor node can fail to function probably due to energy exhaustion and, therefore, leave the sensor network. When a sensor network is deployed initially, all the sensor nodes broadcast a hello message to its 1-hop neighbors. The initial hello message also includes the geographic location of the sending node. After exchanging the initial hello messages, every node knows the identity and location of its 1-hop neighbors. Then every node broadcasts to its 1-hop neighbors the second hello message which includes the identities and locations of the sending node's 1-hop neighbors. After exchanging the second hello messages, every node knows the identity and location of 2-hop neighbors. Then sensor nodes go into the normal operating mode during which every node sends a hello message to its 1-hop neighbors periodically to inform its liveness and identities of failed neighbors, if any.

Now we explain the protocol which builds a multicast tree using nodes in a geocast region. A geocast node N other than the AP node receives from another geocast node M a command packet consisting of a query, a geocast region description, and a sender set. The query and the geocast region description have been originally issued from the sink. When a geocast node broadcasts the command packet to its 1-hop neighbors, it adds its sender set to the command packet. Among its 1-hop neighbors, a node selects some nodes that are invited to rebroadcast the command packet and the set of these selected nodes is called the sender set. If the command is new to N and N is in M's sender The initial geocast command issued from the sink is routed to a first sensor node, which is called an access point(AP) node, in the geocast region using the GEAR protocol described in the previous section. Then using the AP node as a root, a multicast tree is built among sensor nodes either in the geocast region only or in the forwarding region. Figure 2 (a) shows a multicast tree built among nodes in the geocast region which is depicted as a rectangle. The node F cannot join the tree because none of other nodes in the geocast region can reach F in 1 hop. The outer rectangle in Figure 2 (b) is a forwarding region. A forwarding zone for a geocast region is bigger than the geocast region and includes it. If we use the node G which is not in the geocast region but in the forwarding region, the node F can be connected to the tree. If we use nodes which are not in a geocast region but in a forwarding region when we

build a tree, the probability that a geocast region node is not included in the tree due to the hole problem is reduced. In this subsection we describe two protocols for building a multicast tree: one using nodes in a geocast region and the other using nodes in a forwarding region. The decision which protocol to use is made by the sink node and the different command is sent from the sink node.
set, N becomes M's child in the multicast tree. Then N makes its own sender set and sends the command packet to the nodes in its sender set. N's sender set is constructed using a greedy method. Each of N's 1-hop geocast neighbors is checked for the inclusion in N's sender set from the farthest node (from N) to the closest node (from N). A node N's n-hop geocast neighbor set is defined to be the set of all nodes which are N's n-hop neighbors and also in the geocast region. N's 1-hop geocast neighbor node P is included in N's sender set if the inclusion of P's 1-hop geocast neighbor set expands N's 2-hop geocast neighbor set. Following is the pseudo-code description of the algorithm.

```
N receives a command packet from M;
/* command consists of query, geocast region, */
/* and M's sender set */
if (N has seen this command or
     is not in the geocast region)
  return;
/* if new command and in the geocast region, */
/* then become the multicast child of the sender*/
become the multicast child of M and notify it to M;
if (N is not in M's sender set)
  return;
/* N is in the geocast region and chosen to */
/* rebroadcast the command packet */
/* Now N builds its own sender set */
set SENDERS to be an empty set;
/* SENDERS is N's sender set */
set 2H-GN to be an empty set;
/* 2H-GN is N's 2-hop geocast neighbor set */
set 1H-GN to be N's 1-hop geocast neighbor set;
while (1H-GN is not empty) {
  select P from 1H-GN such that M is farthest
    from N;
  remove P from 1H-GN;
  if ((P's 1-hop geocast neighbor ∩  2H-GN)
      is not empty) {
    /* P expands N's 2-hop geocast neighbor set */
    2H-GN = 2H-GN ∪ P's 1-hop geocast neighbor;
    add P to SENDERS}}
if (SENDERS is not empty)
  broadcast  (query, geocast region, SENDERS)
    to N's 1-hop neighbors;
/* M's sender set is replaced with N's sender set */
```

All the geocast nodes other than the AP node run the above algorithm when they receive the command packet. Every node in the multicast tree reports its sensor data to the sink along the multicast tree and any intermediate node can aggregate data received from its child node. The AP node receives a command packet originated from the sink node and the packet consists of the query and the geocast region description. The AP node calculates its sender set using the same method as in the above algorithm, builds a new command packet by adding its sender set, and broadcasts the new command packet to its 1-hop neighbors.

Now we explain the protocol which builds a multicast tree using nodes in a forwarding region. The original command packet issued from the sink node consists of the query, the geocast region description, and the forwarding region description. This command is routed to the AP node in the geocast region using the protocol in GEAR as in the previous protocol. All the nodes other than the AP node in the forwarding region runs the algorithm which is similar to the previous algorithm except that a node considers neighbors in the forwarding region instead of neighbors in the geocast region. So the algorithm is modified as follows.

```
N receives a command packet from M;
/* command consists of query, geocast region, */
/* forwarding region, and M's sender set */
if (N has seen this command or
     is not in the forwarding region)
  return;
become the multicast child of M and notify it to M;
if (N is not in M's sender set)
  return;
/* N is in the forwarding region and chosen to */
/* rebroadcast the command packet */
set SENDERS to be an empty set;
set 2H-FN to be an empty set;
/* 2H-FN is N's 2-hop forwarding neighbor set. */
/* A node N's n-hop forwarding neighbor set is */
/* the set of all nodes which are N's n-hop */
/* neighbors and also in the forwarding region */
set 1H-FN to be N's 1-hop forwarding neighbor set;
while (1H-FN is not empty) {
  select P from 1H-FN such that M is farthest
```

```
    from N;
  remove P from 1H-FN;
  if ((P's 1-hop forwarding neighbor set ∩  2H-FN)
      is not empty) {
    /* P expands N's 2-hop forwarding neighbor set */
    2H-FN = 2H-FN ∪ P's 1-hop forwarding
      neighbor;
    add P to SENDERS}}
if (SENDERS is not empty)
  broadcast  (query, geocast region,
    forwarding region, SENDERS)
    to N's 1-hop neighbors;
```

The resulting multicast tree may have leaf nodes which are not in the geocast region as nodes H and I in Figure 2 (b). Therefore, any subtrees which do not have any geocast node should be pruned from the multicast tree. The pruning phase proceeds as follows. If a multicast node does not receive child node notification packet within a specified time, it considers itself to be a leaf node. If a leaf node is not in the geocast region, it prunes itself from the multicast tree and sends a PRUNE packet to its parent node. A node receiving a PRUNE packet behaves as follows.

```
Node N receives a PRUNE packet from node M;
Remove M from its child list;
if (N's child list is empty and
     N is not in the geocast region) {
  remove itself from the multicast tree;
  send a PRUNE packet to its parent}
```

If a node is in both the multicast tree and geocast region, it reports its sensor data to the sink along the multicast tree and any intermediate node on the multicast tree can aggregate data received from its child node.

4 Discussion

The proposed protocol first finds a route from the sink node to the AP node using the energy efficient algorithm in GEAR and within either the geocast region or forwarding region builds a multicast tree using a new energy efficient broadcasting technique. Therefore, the energy consumption is reduced during the routing path construction phase. Moreover, the resulting multicast tree maximizes the in-network data aggregation among geocast nodes and, therefore, reduces energy consumption during the sensor data reporting phase.

If a multicast tree is built using only the nodes in the geocast region, some sensor nodes may not be included in the tree due to the hole problem. The delivery ratio of a multicast tree is defined as the ratio of the number of geocast sensor nodes on the multicast tree over the total number of sensor nodes in the geocast region. But if we build the tree using nodes in the forwarding region which includes the geocast region, the delivery ratio can be increased. The answer to the question how large the forwarding region should be in comparison with the geocast region depends upon the density of sensor nodes and how much high delivery ratio the sink node desires.

5 Conclusion

In this paper we presented an energy efficient geocast protocol for sensor networks. The protocol first finds a route from the sink node to an access point in the geocast region and then builds a multicast tree which has the access point as the root and the nodes in either the geocast region or forwarding region as intermediate or leaf nodes in the tree. We proposed a new protocol for building a multicast tree using an energy efficient broadcasting technique. The resulting multicast tree facilitates the in-network data aggregation and, therefore, saves energy during the sensor data reporting phase. Then we extended the protocol so that it can be applied to the situation where the geocast region moves as the monitored object moves. In developing the protocol we did not make any assumptions on the shape of geocast region or the predictability of object movement. So the proposed protocol can be used in more general situations. In the future we will analyze the performance of the proposed protocol through the simulation. The performance indices that will be used include the delivery ratio of the multicast tree and the overhead required to build the tree.

References:

[1] Zhang, W., et al, Energy-Aware Location-Aided Multicast Routing in Sensor Networks, *Proceedings WCNM*, 2005, pp. 901-904.

[2] Yao, P., Krohne, E., Camp, T., Performance Comparison of Geocast Routing Protocols for a MANET, *Proceedings of IEEE ICCCN*, 2004, pp. 213-220.

[3] Ko. Y., Vaidaya, N.H., Geocasting in Mobile Ad Hoc Networks: Location-based Multicast

Algorithms, *Proceedings of WMCSA*, 1999, pp. 101-110.

[4] Stojmenovic, I., Voronoi Diagram and Convex Hull Based Geocasting and Routing in Wireless Networks, *University of Ottawa Technical Report,* TR-99-11, 1999.

[5] Ko, Y., Vaidya, N.H., GeoTORA: A Protocol for Geocasting in Mobile Ad Hoc Networks, *Proceedings of ICNP*, 2004, pp. 213-220.

[6] Camp, T., Liu, Y., An Adaptive Mesh-Based Protocol for Geocast Routing, *Journal of Parallel and Distributed Computing*, Vol. 62, No. 2, 2003, pp. 196-213.

[7] Boleng, J., Camp, T., Tolety, V., Mesh-based Geocast Routing Protocols in an Ad Hoc Network, *Proceedings of IPDPS*, 2001, pp. 184-193.

[8] Liao, W.H., et al, GeoGRID: A Geocasting Protocol for Mobile Ad Hoc Networks Based on GRID, *Journal of Internet Technology*, Vol. 1, No. 2, 2000, pp. 23-32.

[9] Yu, Y., Govindan, R., Estrin, D., Geographical and Energy Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks, *UCLA Technical Report*, 2001.

[10] Williams, B., Camp, T., Comparison of Broadcasting Techniques for Mobile Ad Hoc Networks, *Proceedings of MOBIHOC*, 2002, pp. 194-205.

[11] No, S., Tseng, Y., Chen, Y., Sheu, J., The Broadcast Storm Problem in a Mobile Ad Hoc Network, *Proceedings of MOBICOM*, 1999, pp. 151-162.

[12] Lim, H., Kim, C., Multicast Tree Construction and Flooding in Wireless Ad Hoc Networks, *Proceedings of ACM MSWIN*, 2000.

[13] Peng, W., Lu, X., On the Reduction of Broadcast Redundancy in Mobile Ad Hoc Networks, *Proceedings of MOBIHOC*, 2000.

[14] Qayyum, A., Viennot, L., Laouiti, A., Multipoint Relaying: An Efficient Technique of Flooding in Mobile Wireless Networks, *INRIA Technical Report 3898*, 2000.

[15] Peng, W., Lu, X., AHBP: An Efficient Broadcast Protocol for Mobile Ad Hoc Networks, *Journal of Science and Technology*, 2002.

[16] Peng, W., Lu, X., Efficient Broadcast in Mobile Ad Hoc Networks Using Connected Dominating Sets, *Journal of Software*, 1999.

[17] Sucec, J., Marsic, I., An Efficient Distributed Network-Wide Broadcast Algorithm for Mobile Ad Hoc Networks, *Rutgers University CAIP Technical Report 248*, 2000.

[18] Zhang, W., Jia, X., Huang, C., Yang, Y., Energy-Aware Location-Aided Multicast Routing in Sensor Networks, *Proceedings of WCNM*, 2005, pp. 901-904.