An Efficient Geocast Algorithm using 2-hop Neighbour Knowledge in Sensor Networks

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Abstract—Geocast is a mechanism which sends a packet to all the sensor nodes in a certain geographic area. It enables one to collect information from the designated area within a sensor network. Because sensor nodes are operating with limited power source and sending/receiving packets are most energy consuming operations for sensor networks, geocast algorithm should be energy efficient. In this paper we introduce 4 different geocast algorithms using 2-hop neighbor knowledge. We compare their performance using simulation and identify the algorithm with the best performance.

Keywords—Sensor Network, Geocast, Energy Efficiency, Broadcast, Performance Evaluation

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 geocast packets, which are 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.

In sensor networks a group of sensor nodes in a certain geographic region may cooperate to monitor an object within that region. So broadcast to all the sensor nodes in that region becomes essential mechanism. Geocast, a variant of conventional broadcast, 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 GPS(Global Positioning System)[2].

In general geocast routing consist of two phases as in Figure 1. In the first phase a command packet is delivered from the sink node to one or more nodes in the geocast region. Then the packet is broadcast to all the nodes in the geocast region. Although, most proposed geocast protocols for sensor networks focus on the protocol for the first phase and assume the use of flooding for the second phase. GEAR(Geographic and Energy Aware Routing) algorithm is a one notable geocast protocol for sensor networks[3]. It uses energy aware neighbor selection to route a packet towards the geocast region and uses Recursive Geographic Forwarding algorithm to disseminate the packet inside the geocast region. During the first phase, when a node receives a command 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. During the second phase, GEAR disseminates the packet to geocast nodes using a recursive routing algorithm. GEAR proposes an energy efficient protocol for the first phase, but the applicability of its second phase protocol is limited because it can be applied only to rectangular-shaped areas.

In this paper we propose a new energy efficient geocast protocol. We assume the use of algorithms like GEAR for the first phase of the geocast protocol and focus only on the second phase. We propose an energy efficient protocol for disseminating a geocast packet in the geocast region in the sense that the number of sensor nodes which send and receive the geocast packet is minimized. We assume that sensor nodes are not mobile and have knowledge of not only 1-hop neighbors but also 2-hop neighbors. We use...
this 2-hop neighbor knowledge to design an efficient geocast algorithm. In designing an algorithm, we consider two issues: confine the area within which forwarding nodes will be selected and then selecting forwarding nodes within this area. We introduce two alternatives for each issue and, by combining these two issues, introduce 4 different algorithms. We compare the performance of these 4 algorithms through simulation and suggest the algorithm with the best performance.

The rest of the paper is organized as follows. The next section surveys related works. Section 3 describes 4 different geocast algorithms. Section 4 provides the performance evaluation results and suggests the best algorithm. Section 5 concludes the paper.

2. Related Works

Yao et al classified geocast protocols into three categories: flooding-based protocols, routing-based protocols, and cluster-based protocols[2]. But the protocols compared by them focus only on the first phase, simply use flooding mechanism for the second phase, or assume specific shapes for the geocast region. Therefore, their results have only limited applicability for our purposes.

There have been many research works on network wide broadcasting in MANETs and these works can be applied to broadcasting packets in a geocast region in sensor networks. We briefly survey broadcasting techniques in MANETs.

Broadcast techniques in MANETs are classified into four categories: simple flooding, probability based methods, area based methods, and neighbor knowledge methods[4].

The algorithm for Simple Flooding starts with a sink 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[4].

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[5]. 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[4].

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[5]. 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[4].

Neighbor knowledge methods maintain state on their neighborhood, which is used in the decision to rebroadcast. There are Flooding with Self Pruning[6], Scalable Broadcast Algorithm(SBA)[7], Dominant Pruning[6], Multipoint Relaying[8], Ad Hoc Broadcast Protocol(AHBP)[9], Connected Dominating Set(CDC)-Based Broadcast Algorithm[10], and Lightweight and Efficient Network-Wide Broadcast(LENWB)[11] in this category. Among them, we describe first two protocols. The Flooding with Self Pruning protocol requires that each node has 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

![Figure 1 - 2 phases in geocast routing](image-url)
receiving a broadcast packet compares 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[4].

3. Description of Geocast Routing Protocol

As we explained in the introduction, we assume that geocast protocol consists of two phases. The initial geocast packet issued from the sink node is routed to a certain sensor node in the geocast region using protocols as in GEAR and then the packet is distributed to all the sensor nodes in the geocast region. We focus only on the second phase of the protocol in this paper.

As a sensor node consumes energy the most when it transmits and receives a packet, we try to minimize the number of sensor nodes which forward the geocast command in the geocast region. We aim to achieve this goal by making sensor nodes utilize knowledge of their 2-hop neighbors while distributing geocast packets in the geocast region. 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 outline of the protocol which broadcasts a geocast packet in a geocast region. A geocast node N receives from another node M a geocast packet consisting of a query or command, a geocast region description, and a forwarder set. The query/command and the geocast region description have been originally issued from the sink. When a geocast node broadcasts the packet to its 1-hop neighbors, it adds its forwarder set to the packet. Among its 1-hop neighbors, a node selects some nodes that are invited to rebroadcast the packet and the set of these selected nodes is called the forwarder set. If the packet is new to N and N is in M’s forwarder set, N calculates its own forwarder set, includes it in its geocast packet, and broadcasts the packet. This process is continued until no geocast node can find a non-empty forwarder set.

The process of calculating a forwarder set may consist of two steps. In the first step, the range confinement step, the range in which a node’s 1-hop neighbors and 2-hop neighbors will be considered is confined and in the second step, the node selection step, the forwarder set is calculated within the confined range.

![Figure 2 - Range confinement strategies](image)

In Figure 2, we assume that sensor node N received a geocast packet from the node M. To calculate N’s forwarder set, we have to consider N’s 1-hop neighbors and 2-hop neighbors. But as in Figure 2 (a), we can basically eliminate M’s 1-hop neighbor range from consideration, because all the nodes in M’s 1-hop neighbor range must have...
received the geocast packet. We call this strategy the basic confinement. In Figure 2 (b) we draw a line from M to N and then draw a vertical line at N. We assume that with a high probability nodes which are located to the left of this vertical line have received the geocast packet already and, therefore, take these nodes out of consideration. We call this strategy the advanced confinement. So when we calculate N’s forwarder set in the next step, we consider 1-hop neighbors in the gray area and 2-hop neighbors in the hatched area.

For the second step, two greedy methods have been proposed in the past[6,12]. In Shim’s method, a sensor node N’s 1-hop geocast neighbors is checked for the inclusion in N’s forwarder set from the farthest node (from N) to the closest node (from N)[12]. In Lim’s method, a sensor node N’s 1-hop geocast neighbors is checked from the node which has the most number of 1-hop neighbors to the node which has the least number of 1-hop neighbors[6]. We call Shim’s method to be the longest distance first method and Lim’s method to be the most neighbors first method. Following is the pseudo-code description of these two methods.

Set FWRD to be an empty set;
/* FWRD is N’s forwarder set */
Set 2H-GN to be an empty set;
/* 2H-GN is N’s 2-hop geocast neighbor set */
Sort N’s 1-hop neighbors and store them in 1H-GN;
/* In Shim’s method, neighbors are sorted by the their distance from N */
/* In Lim’s method, neighbors are sorted by the number of their 1-hop neighbors */
While (1H-GN is not empty) {
    Remove the first node P in 1H-GN;
    If ((P’s 1-hop geocast neighbor ∩ 2H-GN) is not empty) {
        2H-GN = 2H-GN ∪ P’s 1-hop geocast neighbor;
        Add P to FWRD}
}

We explained two strategies for the range confinement: basic confinement(BC) and advanced confinement(AC).

Then we described two selection methods: longest distance first(LDF) and most neighbors first(MNF). Now we can combine these methods and have 4 algorithms for calculating the forwarder set as follow.

- BC-LDF: basic confinement and longest distance first
- AC-LDF: advanced confinement and longest distance first
- BC-MNF: basic confinement and most neighbors first
- AC-MNF: advanced confinement and most neighbors first

In the next section we compare performance of these 4 algorithms using simulation and suggest the best algorithm.

4. Performance Evaluation

In this section we evaluate the performance of 4 algorithms explained in the previous section through simulation. To determine the simulation environment, we first determine the node density which provides the satisfactory success rate of packet delivery in the geocast region using simulation. Then we compare performance of 4 algorithms along with the flooding method using simulation. Metrics used to compare the performance are the number of nodes which send the packet and the number of nodes which receive the packet during the broadcast in the geocast region. These metrics are chosen because sending and receiving packets are most energy consuming operations for sensor nodes and we have to minimize the number of nodes sending and/or receiving packets to minimize energy consumption in sensor networks.

4.1 Determination of Sensor Node Density

We assume that the geocast region is a square with the area of 1Km² and the communication range of a node is a circle with the radius of 25m. We increased the number of nodes from 500 to 2000 and measured the delivery success rate, which is defined to be the ratio of the number of nodes which received the geocast packet to the number of all nodes in the geocast region. For this experiment, we used flooding algorithm. Table 1 and figure 3 show the experimentation result. Figure 3 shows that delivery success rate reaches almost 100% if the average number of nodes in the sensor node’s communication range is 2 or higher and it falls sharply if average number of nodes is lower than 1.4. From this result, we vary the average number of nodes from 1.4 to 2.6 in the experiments for comparing performance of algorithms.

4.2 Performance Comparison of 5 Algorithms

We compare the performance of 4 algorithms introduced in Section 3 along with the flooding algorithm by measuring the number of nodes sending and receiving a geocast packet. Figure 4 shows the result. Figure shows that the numbers of sender nodes and receiver nodes increase as the node density increases. It also shows that the flooding algorithm has the highest numbers of nodes while the other 4 algorithms exhibit almost half numbers of nodes compared with the flooding algorithm.
We now compare the 4 algorithms excluding the flooding algorithm. Between two range confinement methods, the advanced confinement method performs better than the basic confinement method. This result can be quite obvious because the latter method eliminates more unnecessary forwarder nodes than the former method. Between two node selection methods, the most neighbor first method performs better than the longest distance method. From this result we can conclude that the AC-MNF method has the best performance. But this conclusion can have meaning only if the considered algorithms have the similar delivery success rate as the flooding method. Table 2 shows that this is true and we can safely conclude that the AC-MNF algorithm has the best performance.

Table 2 - Delivery success rate of geocast algorithms

<table>
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<tr>
<th>Avg. # of nodes in communication range</th>
<th>Flooding</th>
<th>BC-LDF</th>
<th>AC-LDF</th>
<th>BC-MNF</th>
<th>AC-MNF</th>
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5. Conclusion

Geocast is a mechanism which sends packets from a sink node to all the sensor nodes in a certain geographic area. Because sensor nodes are operating with limited power source, it is important to develop an energy efficient geocast protocol.

A geocast protocol consists of two phases. In the first phase a geocast packet is unicast from the sink node to a node in the geocast region. In the second phase the packet is broadcast from that geocast node to all the nodes in the geocast region. In this paper we considered only the second phase and introduced 4
different algorithms. Each algorithm uses 2-hop neighbor knowledge and tries to minimize the number of nodes which forwards the geocast packet during the broadcast phase to reduce energy consumption. We compared performance of 4 algorithms along with the flooding algorithm and found out the advanced confinement and most neighbor first algorithm had the best performance without degrading the delivery success rate.

Acknowledgments

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References


