A Novel Gradient Approach for Efficient Data Dissemination in Wireless Sensor Networks

Kook-Hee Han, Young-Bae Ko and Jai-Hoon Kim
Graduate School of Information and Communication,
Ajou University, Republic of Korea
{justuniq, youngko, jaikim}@ajou.ac.kr

Abstract — **In wireless sensor network, a majority of packet transmissions are delivered in the direction of a sink from scattered sensors. Thus, each sensor node can be implicitly provided the direction to forward sensing data towards the sink. Most existing gradient approaches are based on this observation. However, these approaches do not consider a mobility problem. In this paper, we propose a new gradient flooding protocol in which only hop count information is utilized as a cost metric for gradient forwarding and each sensor is able to self-adjust this metric with the minimum overhead whenever its movement occurs.**

Index Terms — **Gradient-based routing, Wireless sensor networks, Mobility**

I. Introduction

Recent advances in short range radio technologies and Micro-Electro Mechanical Systems (MEMS) have led to the development of embedded smart sensors, which are generally equipped with capabilities of sensing, computing, and wireless communication in severely resource constrained devices. These tiny sensor nodes can be deployed in various (often, harsh) environments to collectively gather some interesting data and to deliver them into a centralized monitoring units – called the sink. Such a sensing data delivery towards a sink may include a large number of wireless hops among the networked set of small, resource-limited sensor nodes. This characteristic makes the problem of data dissemination in wireless sensor networks (WSN) become non-trivial [1].

Several algorithms and protocols have been proposed in the last few years, with the goal of achieving more efficient and reliable data dissemination in WSN. Clearly, a flooding is the most reliable scheme to forward data from sensors to a sink. With no extra cost for topology maintenance or route discovery, it is very simple and easy to implement. However, flooding may suffer from significant redundancy with too many duplicated messages in a network. This is especially inefficient in terms of energy consumption. To solve this problem, a new data centric approach, different from traditional node-based routing approach, has been developed for WSN. Data centric protocols are motivated by the fact that most of applications for sensor networks rather focus on "data" generated by sensors, and are even not interesting in sensor nodes themselves. They are query-based and dependent on the naming of desired data (i.e., data named by attribute-value pairs). Therefore, many redundant packet transmissions can be avoided, resulting in energy efficiency. SPIN [2] and Directed Diffusion [3] are the two representative protocols in data centric routing. Especially, Directed Diffusion has become the probably most popular and often-cited data centric protocol, with its several properties for energy conservation such as on-demand data querying (called interests) by the sink, data aggregation and caching by the sensors, and gradient/reinforced path setup mechanism.

The concept of "gradient" usually means a direction state, set towards the neighboring nodes through which a destined sink is reached. In wireless sensor networks, a majority of packet transmissions are delivered in the direction of a sink from scattered sensors. Thus, each sensor node can be implicitly provided the direction to forward sensing data to the sink. Based on this observation, a gradient routing approach has been utilized for WSN. Some protocols based on this approach are [4, 5, 6]. A common idea of these protocols is to make the locally optimal choice of next hop as the neighbor "closer" to the sink so that sensing data can follow the direction of descending gradient to reach the sink.

One important assumption here is that the value of gradient needs to be built and maintained at each node. In general, such a gradient value management is achieved by initial and periodic flooding of some form of control packets (e.g., 'interest' in Directed Diffusion [3] or 'advertisement' in GRAB [6]) from a sink. Note that this periodic flooding throughout the whole network may cause excessive overhead (in terms of energy and bandwidth consumption) in sensor networks. Moreover, when network topology changes due to a sensor node failure, wireless link breakage, or mobility, some gradient value will become inaccurate and hence requires more frequent flooding. To remedy this inefficiency problem, we propose an improved version of the gradient-based routing protocol.

The rest of paper is organized as follows. Related work on gradient based sensing data dissemination approach is covered in Section II. Section III introduces our novel gradient flooding

This work was in part supported by Korea Research Foundation Grant (KRF-2003-003-D00375), University IT Research Center Project, by ITA Professorship for Visiting Faculty Positions in Korea (International Joint Research Project).

scheme, followed by ns-2 simulation study and results in Section IV. We conclude in Section V.

II. Related Work

There has been recent research interest on routing in wireless sensor networks. The most well known protocol is Directed Diffusion [3], where a sink queries the sensors in an on-demand fashion by disseminating an interest, i.e., a list of attribute-value pairs for the desired data, in order to build reverse paths from all potential sensing sources to the sink. This reverse path vector is named a "gradient" in [3]. By utilizing interest and gradients, paths (possibly multiple) are established between sink and sources. Directed Diffusion uses the reinforcement mechanism to select a high quality path for the data flow among multiple paths available. It is important to note that, in Directed Diffusion, each node forwards a packet to a specific next hop neighbor along the reinforced path.

[4] has proposed a slightly modified version of Directed Diffusion, named Gradient-Based Routing (GBR). In GBR, while being diffused through the network, the interest message is required to record the number of hops taken from the sink. This allows each node to discover the minimum number of hops to the sink, called 'height' of the node. A gradient here is defined as the difference between a node's height and that of its neighbor. Note that a sensor data packet is forwarded on the link with the largest gradient. GBR uses data traffic spreading techniques for load balancing and network lifetime increase. However, it still suffers from inherent drawback of wasting energy with periodic interest message dissemination.

A similar concept of gradient-based routing was recently presented in [5], by exploiting "decay pattern" of event's effect. More recently, GRAB (GRAdient Broadcast) protocol has been proposed [6]. The basic idea is to make data packets issued by a sensor (called, a data source) be delivered along the direction of a sink by descending some cost, which are initially built and maintained by the sink but kept by each sensor. The cost at a node in GRAB is the minimum energy overhead to forward a packet from itself to the sink along a path. Sensors closer to the sink will have smaller costs of energy overhead. When a node forwards a packet, it simply includes its own energy cost in the packet. On receiving this packet, neighbors will participated in a packet forwarding process *only when* its own cost is smaller than that of the previous sender. Multiple paths of decreasing cost may exist and interleaved forwarding mesh will be formed; hence, the authors argue that GRAB is a robust and reliable data delivery method.

GRAB also requires each node's cost value to be periodically refreshed by a sink (using an advertisement (ADV) packet), causing the same problem of excessive overhead. Therefore, this scheme may not work well in dynamic environments, even in a semi-static environment with low mobility. As mentioned earlier, we propose a new gradient flooding protocol to remedy this problem. In our protocol, "hop count" information is utilized as a cost metric for gradient forwarding and each sensor is able to self-adjust this metric with the minimum overhead whenever its topology change occurs. Such an adjustment phase will be done in a distributed manner, unlike other protocols described above. Thus, our contribution is to propose more efficient and reliable gradient flooding protocol that works for sensor networks under low mobility. We should mention that the proposed scheme may work for more dynamic environments as well, but with increasing overhead.

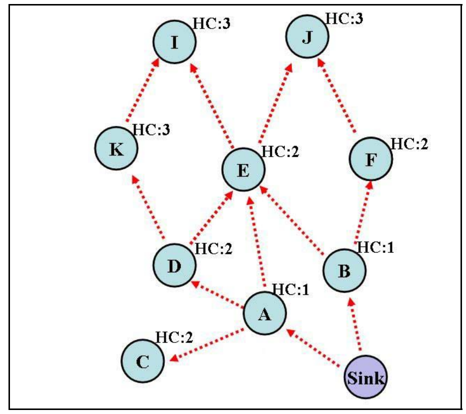

Fig.1 Gradient Setup Phase: INIT packet is initially flooded by a sink and utilized for gradient (i.e., hop count: HC) setup at each sensor.

III. Proposed Gradient-Based data Dissemination

The proposed scheme in this paper also belongs to a gradient flooding mechanism in that it utilizes "hop count information" of sensors towards a sink for packet forwarding. The protocol has three phases: Gradient setup phase, Data dissemination phase, and Gradient reconfiguration phase.

A. Gradient Setup Phase

To setup initial gradient values of sensors, a sink node floods its neighbors a short initiation message (INIT). This INIT message contains a hop count cost of 0, set by the sink. Every sensor node maintains its minimum hop count to the sink (HC), which is initially set as its default value of NULL. When receiving a first INIT packet, a node sets its HC value to the INIT's hop count value *plus* 1 -- see Fig. 1, where node A's HC value is being set to 1. The node then re-sends INIT to all of its one-hop neighbors after replacing the INIT's hop count cost value by its new HC value; thus, the INIT packet sent by node A contains hop count cost of 1. This process continues until all sensors set their HC values accordingly by receiving INIT packets at least once (unless they are network partitioned).

Note that INIT packet propagation will terminate eventually because any node receiving duplicate INIT packets must discard them without a further broadcast. Also, note that the sink is required to broadcast an INIT packet only once, but not periodically.

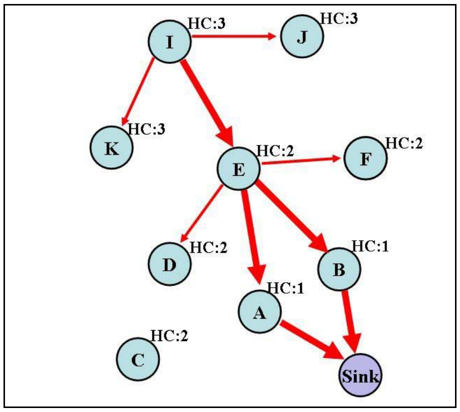

Fig. 2 Data Dissemination Phase: DATA packets follow the decreasing cost (i.e., HC value) direction towards the sink.

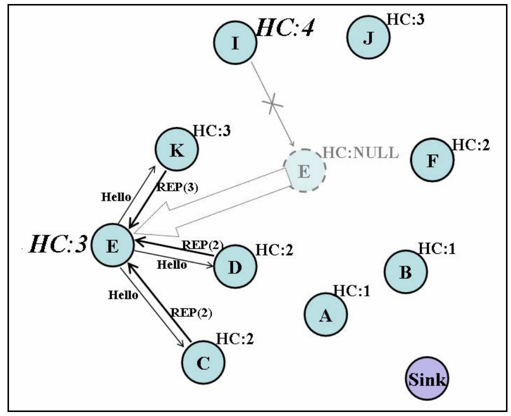

Fig. 3 Gradient Reconfiguration Phase: HELLO and REP packets are locally exchanged to self-reconfigure moving nodes' HC values.

B. Data Dissemination Phase

In this phase, a source node detecting any events can simply transmit data packets (DATA) to its neighbors via the radio channel (i.e., without appointing any specific neighbor as the next hop). This DATA packet may contain not only an event description but also the source node's hop count (HC) value. Each receiving node then independently decides whether it should further forward the DATA or not. That is, a node that receives a DATA packet compares this DATA's HC value to its own value of HC. If its own HC value is equal to or larger than the DATA's HC, the node silently drops the DATA packet. Otherwise, the node should forward the DATA to its neighbors. This forwarded DATA packet now contains a new HC value that is equal to the forwarding node's minimum hop count to the sink.

Fig. 2 illustrates how data dissemination initiated by node I can be made in a gradient fashion towards a sink. Since node I includes its own hop count value (i.e., HC=3) with a data packet, its neighbor nodes E, J and K can compare it to their own HC values in order to make a forwarding decision. The figure shows that node E will only be allowed to forward DATA because its hop count (HC=2) is less than that of DATA, whereas the other two neighbor nodes J and K will just drop it because their HC values (HC=3) are not smaller than the DATA packet's HC value of 3. This process is continued till the data packet reaches the sink node.

Note that no forwarding loop can form in this phase because DATA packets from a source can always and only follow along the decreasing cost (in terms of hop count) direction toward the sink. Also, reliable data delivery can be achieved, by exploiting the redundancy from disjoint multi-paths between a source and a sink. Multiple copies of data that are sent along different paths allows for resilience to failure of a certain number of paths – again, consider Fig. 2 that the sink receives multiple copies of the same data packet via the two different routes. Of course, utilizing multiple paths may come at the possible expense of increased energy so there is a tradeoff between reliable data dissemination and energy conservation.

Remind that a sender of DATA packet does not decide which neighbor to continue forwarding; it is totally up to a receiving neighbor with its HC value. In fact, this property may be good for the end-to-end reliability as it may increase the likelihood of multiple disjoint paths.

C. Gradient Reconfiguration Phase

Hop count information of a sensor depends on the topology. Therefore, any topology changes will have the nodes' HC value become inaccurate. Among several factors that cause the topology change, node mobility[1] would be a dominating one. When a sensor moves and changes its position, its current hop count value (initially set during the gradient setup phase) may no longer be valid. Hence, its hop count (HC) value needs to be adjusted accordingly.

In this paper, we assume a semi-static environment, where sensor nodes are not static but moving intermittently. In our mobility model, each node stays for relatively long pause time before starting to move again. We also assume that each sensor has capability for detecting its moving state. Thus, sensors can be aware of whether they are on move (i.e., moving state) or on pause (i.e., pause state). Any node that goes to a moving state is required to reset its HC value as NULL so that it can be prevented from participating in the data dissemination phase; thus, moving nodes are not involved in packet forwarding process at all. After the node stops moving and returns back to a pause state, it tries to re-configure its HC value locally and in a distributed manner. Recall that most of existing gradient-based protocols are based on a global reconfiguration mechanism, relying on a periodic broadcast from a sink. This localized gradient reconfiguration phase will be explained with our example.

We now further elaborate on the gradient reconfiguration phase using Fig. 3. In this case, let us assume that node E with HC value of 2 is on move, and therefore it goes to a moving state. Observe that its HC value is being reset to NULL in the figure. When node E completes its movement, it sends a hello message (HELLO) to its one-hop neighbors (nodes C, D, and K in our example) and waits for answers about their hop count values for some amount of time. After receiving all the replies

[1] In general, no or less mobility is considered in wireless sensor networks. However, there is recent interest in adding controllable mobile components into embedded sensor networks for more predictable and larger gains [7].

(REP messages) from its neighbors within some timeout, node E finds the smallest hop count value among them. Node E then sets its new HC value as that smallest hop count *plus* 1; hence, node E's HC value is reconfigured as 3 now.

This procedure of gradient value reconfiguration (caused by moving nodes) is summarized below:

```
IF moving state THEN
   /*not participate routing*/
   hop Count ← NULL
   WHILE hop count is null
      IF pause state THEN
         flood HELLO message to neighbor nodes

         WHILE waiting time
               receive REP message about HELLO
               IF hop count  THEN
                     IF hop count > REP +1 THEN
                           hop Count ← REP +1
                     ENDIF
               ELSE
                     hop Count ← REP +1
               ENDIF
         ENDWHILE

      ENDIF
   ENDWHILE

ENDIF
/*go to data dissemination phase*/
```

Sometimes, even non-moving nodes are involved in the gradient reconfiguration phase. Fig. 3 illustrates this scenario as well; observe that node I has never been on move but its HC value has become 4. This indicates that node I also performs the gradient reconfiguration phase (explained above) when it becomes aware of the fact that its immediate forwarding node E disappears. Node I can be aware of this in its data delivery phase when it cannot overhear of any re-broadcast for its own DATA packets. Once node I notices this fact, it tries to verify about the correctness of its HC value by the HELLO-REP packet exchange mechanism.

IV. SIMULATIONS AND RESULTS

In this section we evaluate the performance of our scheme through ns-2 simulator [8]. We use the following model for our simulation study:

- Initially, sensor nodes are uniformly distributed in a confined space of 200m×200m.
- Nodes' transmission range is defined as 30m
- Nodes' energy model in the current ns-2 is utilized (i.e., Tx power: 0.660 Joules, Rx power: 0.395 Joules, Idle power: 0.035 Joules)
- Total simulation time is 1000 seconds.
- Initial node energy is 1000 Joules.
- The size of DATA packet is 64bytes and that of control packets (INIT, HELLO, and REP) is 20 bytes.

In our simulation model, the number of nodes in the network was chosen to be 100, 200, 300 and 400 for different simulation runs. We ran our simulations with movement patterns generated for two different pause times: 500 and 1000 seconds. A pause time of 1000 sec is equivalent to static networks with zero mobility because our total simulation time is 1000 sec. A pause time of 500 sec corresponds to semi-static networks, where the average speed of each sensor node is 3 m/s (i.e., the minimum speed of 1 m/s and the maximum speed of 5 m/s).

One of the sensor nodes is randomly chosen as the source for initiating data packet dissemination at a time. During the total simulation time of 1000 sec, 100 data packets are generated. We compare the performance results of the proposed scheme with those of the pure flooding and the simplified gradient-based scheme (we call it as "Basic Gradient").

- Basic Gradient Scheme: In our implementation, this scheme has gradient setup and data dissemination phases. But, it does not perform the gradient reconfiguration phase as explained in the previous section. Instead, in this scheme, a sink is implemented to generate and flood the INIT message periodically for the purpose of gradient reconfiguration. For the static scenario, a sink generates INIT packet every 4 sensing event occurrence (approximately, every 40 sec – note that periodic interest propagation is done every 5 sec in the current ns-2 implementation of Directed Diffusion [3]). For the semi-static scenario, the frequency of INIT packet generation becomes increased by every event occurrence (i.e., about every 10 sec – also, note that no mobile scenario is implemented for Directed Diffusion in ns-2).

We use two performance metrics to measure the energy efficiency and the overhead. For energy efficiency, the *total dissipated energy* is measured as the total consumed energy by all the nodes in the network. For the overhead, we use the total number of bytes transmitted by all nodes. In the pure flooding, the overhead is due to only data packets, but in Basic Gradient and our scheme it can be due to data as well as control packets.

Fig. 4 and 5 shows the total dissipated energy of the three data dissemination protocols as a function of the number of nodes, when a network is static and semi-static, respectively. As can be expected, the pure flooding consumes much more energy than the Basic Gradient and the proposed novel gradient scheme in all cases. Both gradient-based approaches achieve such energy efficiency by reducing the huge number of redundant data disseminations. Total dissipated energy of the Basic Gradient is low (compared to the flooding), but not as low as the proposed gradient scheme. The main reason for this is that, in Basic Gradient, INIT packets are periodically flooded throughout the whole network by the sink. These periodic broadcasts may occur even more frequently in semi-static networking environments – that is why the total dissipated energy of the Basic Gradient is larger in Fig. 5 than Fig. 4. The total consumed energy is consistently lower for the proposed gradient scheme even though it slightly increases with increasing node mobility (i.e., decreasing pause time). Recall that the proposed scheme localizes the gradient reconfiguration

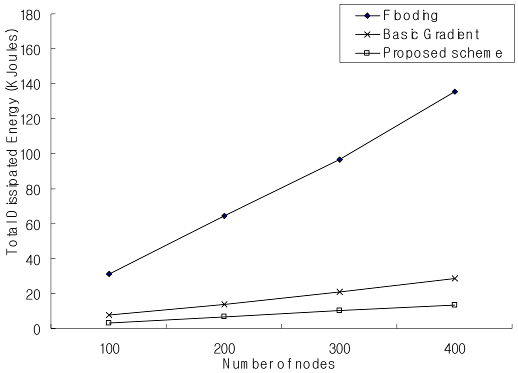

Fig.4 Total dissipated energy by all nodes versus The number of nodes (in static network with zero node mobility)

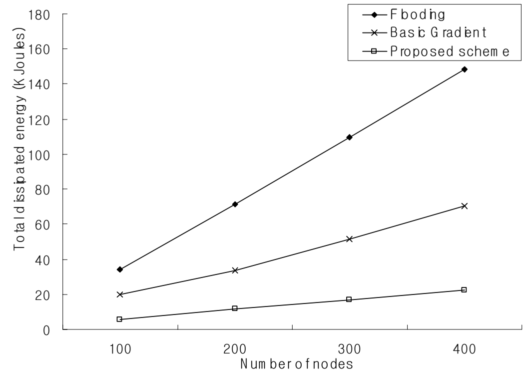

Fig.5 Total dissipated energy by all nodes versus The number of nodes (in semi-static network with node pause time of 500 sec)

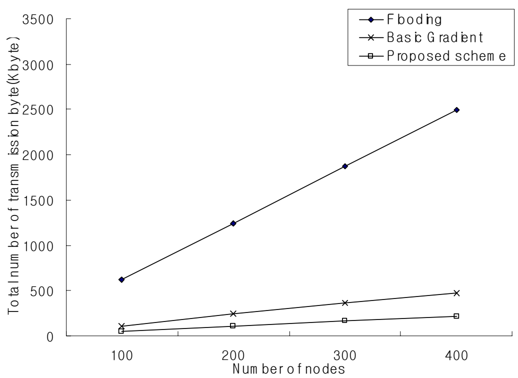

Fig. 6 Total number of bytes in the network versus The number of nodes (in static network with zero node mobility)

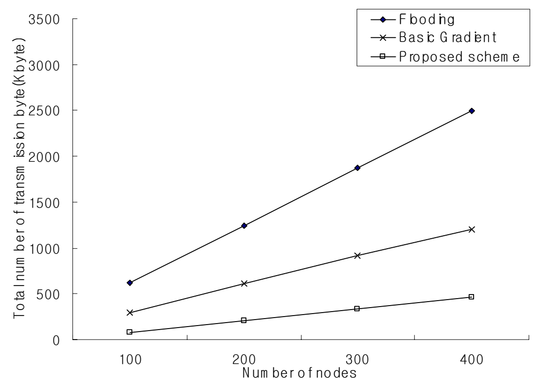

Fig. 7 Total number of bytes in the network versus The number of nodes (in semi-static network with node pause time of 500 sec)

phase and limits the scope of flooding to the nodes located next to any moving nodes. Thus, degree of flooding is smaller in the proposed scheme, compared to the Basic Gradient scheme. This results in the lower energy consumption of our protocol.

Fig. 6 and 7 plot the total number of bytes transmitted by all nodes, as a function of the number of nodes, in static networks and in semi-static networks, respectively. Similar to the results of the previous figures, both flooding and Basic Gradient have much larger byte overhead than the proposed scheme. This means that a larger part of bandwidth is wasted with other two protocols. The curves for the proposed gradient protocol byte overhead in static networks, and in semi-static networks are almost same because the size of control packets (i.e., HELLO and REP packets) is relatively small.

In short, the proposed scheme is capable of saving significant energy against unnecessarily duplicated data transmissions and global control packet transmission overhead.

V. Conclusion

In this paper, we present a new gradient approach for efficient data dissemination in wireless mobile sensor networks. In this scheme, a desired node sends HELLO to one-hop neighbors to locally adjust its own gradient value. Our work is motivated by a gradient-based approach, which does not consider mobility. Using proposed scheme, we can not only remove unnecessary flooding in the whole network, but also self-reconfigure the gradient information by mobility adaptive method. We believe that our proposed scheme can effectively solve the problem in an energy efficient manner.

References

[1] I.F. Akyildiz, et. al., “Wireless sensor networks: a survey,” Computer Networks, Vol. 38, March 2002, pp.393-422.
[2] W. Heinzelman, J. Kulik, and H. Balakrishnan, “Adaptive protocols for information dissemination in wireless sensor networks,” MobiCom’99, Whashington, US, 1999.
[3] C. Intanagonwiwat, et. al., “Directed Diffusion: A scalable and robust communication paradigm for sensor networking,” MobiCom’00, Rome, Italy, 2000.
[4] C. Schurgers and M.B Srivastava, “Energy efficient routing in wireless sensor networks,” MILCOM’01.
[5] J. Faruque and A. Helmy, “Gradient-based routing in sensor networks,” Mobile Computing and Communication Review, Vol. 7(4), 2003, pp.50-52.
[6] F. Ye, G. Zhong, S. Lu, and L. Zhang, "GRAdient broadcast: A robust data delivery protocol for large scale sensor networks," To appear ACM Wireless Networks, Vol. 11(2), March 2005.
[7] A. Kansal, et. al., “Intelligent fluid infrastructure for embedded networks,” MobiSys’04, Boston, US, 2004.
[8] ns2 network simulator. http://www.isi.edu/nsnam/ns.