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Circle Path Based Sink Location Service for Geographic Routing Scheme

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Abstract*—Geographic routing has been considered as an efficient, simple, and scalable routing protocol for wireless sensor networks since it exploits pure local location information instead of global topology information to route data packets. Geographic routing requires the sources nodes to be aware of the location of sinks. Most existing geographic routing protocols merely assume that source nodes are aware of the locations of sinks or can get the locations of sinks by some service. How can source nodes get the locations of sinks was not addressed in detail. In this paper, we propose a Circle Path Based Sink Location Service for Geographic Routing in wireless sensor networks. In this scheme, a source node sends a Sink Location Query (*SLQ*) message to the predefined Base Node and sends another *SLQ* message to a node on the edge of the sensor network, thus generating a *SLQ* path; a sink node sends a Sink Location Announcement (*SLA*) message along a circle path, the centre of the circle path is the predefined Base Node. By this way we can guarantee the *SLQ* path and *SLA* path have at least one crossing point. The node located on the crossing point of the two paths informs the source node the sink location. How to achieve this procedure in any irregular profile sensor network is another challenge of this paper. Simulation results show that our protocol is significantly superior to other protocols in terms of energy consumption and control overhead.

Keywords-Sensor networks; location service; geographic routing

I. INTRODUCTION

Geographic routing[1] has been considered as an attractive approach since it exploits pure local location information instead of global topology information to route data packets. This location based routing scheme makes it a more efficient, simple and scalable routing protocol in wireless sensor networks. In geographic routing scheme, a source node encapsulates the sink location in each data packet. After received a data packet, a node sends it to the one-hop neighbor which is geographically closest to the sink. This process repeats until the data packet is eventually received by the sink. This mechanism can minimize the routing hops from the source to the sink. Geographic routing requires three necessary conditions, i.e., First, each node must know its own location information, GPS or other location service [7][8] can fulfill this requirement; Second, each node must know the location of its one-hop neighbor nodes. This requirement can be fulfilled by beacon messages [1]; Third, the source node must know the location of the sink. In wireless sensor networks, source nodes and sinks may exist in anywhere in the network and even can move. General GPS service can not provide the source nodes with the locations of sinks. Some well-known geographic routing schemes [1] [2] [3] [4] just merely assumed that source nodes are aware of the location of sinks by some service, how can the source nodes get the sink locations are not addressed in detail.

Flooding[5] is the simplest method for providing the source nodes with the sinks location information. Specially, a sink floods its own location information throughout the sensor network, thus all source nodes in the network can get the location of the sink. This flooding method consumes lots of network resources such as energy and bandwidth if multiple mobile sinks exist in the network.

To avoid the flooding overhead incurred for providing the source nodes with the locations of sinks, a grid-based protocols, named TTDD [6] were proposed. TTDD periodically constructs per-source based global grid structures, each grid point is associated with a dissemination node and each dissemination node is aware of its upstream and downstream dissemination nodes. A sink node broadcasts a data query message within about a grid cell size area to find a nearest dissemination node. The query message is relayed by a series of dissemination nodes and eventually received by the source node. Then the source node sends data packets to the sink along the reverse path of the query message. Flooding query messages only within about a grid cell size is an efficient way, however, the bigger the cell size, the wider the flooding area, thus the more flooding overhead, while small grid size incurs more overhead for the grid construction. Periodic per-source based global grid constructions also significantly generate additional overhead.

In this paper, to minimize the overhead incurred for providing sources with the locations of sinks, we propose a Circle Path Based Sink Location Service for Geographic Routing in wireless sensor networks. In this scheme, a source node sends a Sink Location Query (*SLQ*) message to the predefined *Base Node* and sends another *SLQ* message to a node on the edge of the sensor network, thus generating a *SLQ* path; a sink node sends Sink Location Announcement (*SLA*) messages along a circle path, the centre of the circle is the predefined *Base Node*. By this way we can guarantee the *SLQ* and *SLA* paths have at least one crossing point. The node located on the crossing point of the two paths informs the

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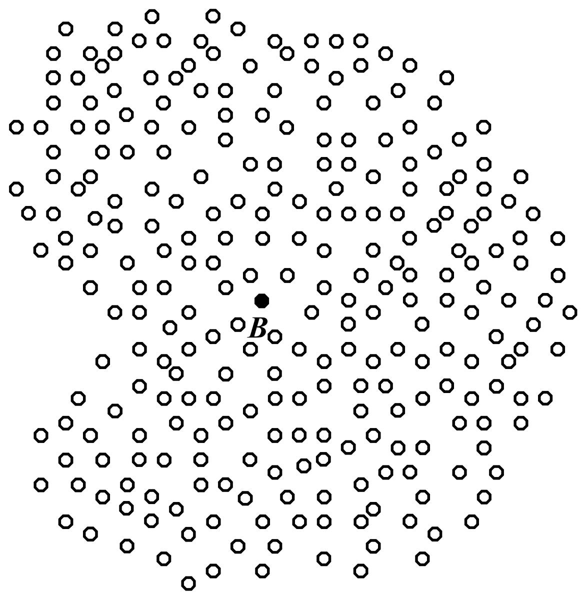

Figure 1. A general sensor network.

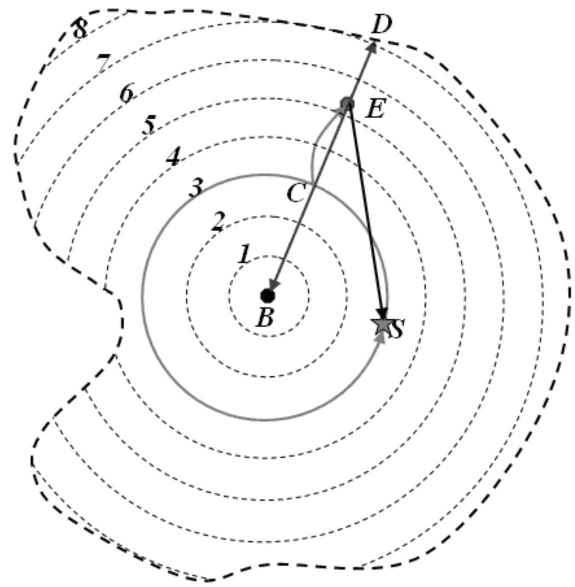

Figure 2. Network initialization and the proposed sink location service.

source node about the sink location. Then the source node can send data packets to the sink by geography routing. There is no flooding and redundant signaling during sink location announcement/query phase. The challenge is that how to achieve this procedure in any irregular profile of sensor networks.

The rest of this paper is organized as follows: Section Ⅱ describes the proposed Circle Path Based Sink Location Service for Geographic Routing scheme in detail. Analysis is given in section Ⅲ, Section Ⅳ describes the simulation and performance evaluation of the proposed scheme, and section Ⅴ concludes this paper.

II. THE PROPOSED SCHEME

We assume in this work that each node can get its own location information either by GPS or other location services [7][8]. Each node can get its one-hop neighbor list and their locations by beacon messages [1]. A node can know whether it is located on the edge of a sensor network either by manual identification during network deployment, or by some automatic detection method [9][10] after network deployment.

In our scheme, a sink sends *SLA* message along a circle path, and a source node sends *SLQ* message along a line path. To navigate the delivery of the *SLA* and *SLQ* packet, all sensor nodes need to get some information of network after the network deployment.

A. Network Initialization

After network deployment, a node named *Base Node* is selected in the sensor network. The *Base Node* initializes a *Network Initialization* (NI) packet and floods it to the whole network. This NI packet contains *B_N_Location* field which is the location of the *Base Node*. Each sensor node maintains a *Height* value. The Height value is calculated as follows:

$$Height = \left\lceil \frac{L}{R} \right\rceil \qquad (1)$$

Where, L is the distance form itself to the *base node*, R is the radio range of sensor nodes.

Fig.1 shows a general sensor network. The selected *Base Node B* initializes a NI packet which *B_N_Location* field is set to the location of node B, node B floods the NI packet throughout the whole sensor network. When a node receives the NI packet, the node saves the *B_N_Location* and calculates its *Height* value based on the base node location and its own location, and then rebroadcasts the NI packet to its neighbor nodes. Duplicated received NI packets are slightly discarded. Fig.2 shows the ideal result of this process, where the thick dotted curve line indicates the edge of the sensor network, and the thin dotted circles are the traces of the sensor nodes which have the same *Height* value. To facilitate discussion, all general sensor nodes are not drawn out here. After the network initialization phase, all sensor nodes are aware of the *Height* value of themselves and the location of the *Base Node*. By beacon messages [1], all nodes can get the *Height* value of their neighbor sensor nodes.

B. Sink Location Service

This section will describe the proposed sink location service. As shown in Fig.2, when a sink S exists in the sensor network, it gets a *Height* value by querying neighbor sensor nodes. Then it initializes a *Sink Location Announcement* (*SLA*)

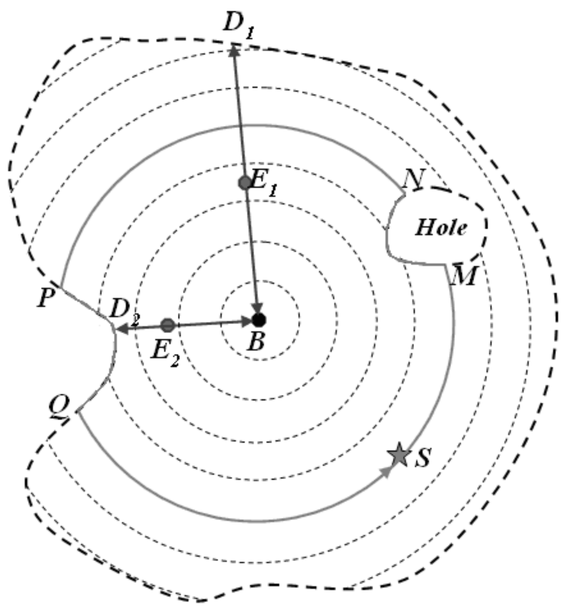

Figure 3. The proposed sink location service in a any profile sensor network

message, which contains the following fields: *Sink_Location, Sink_Interest, Height, and Direction*. The *Sink_Location* field is set to the location of the sink *S* and the *Sink_Interest* field is set to the interest of the sink *S*, the *Height* field is set to the value gotten from neighbor node and the *Direction* field is set to *left*. Then the sink node *S* sends the *SLA* packet to the farthest neighbor sensor node on the left side of itself which has the same *Height* value. When the node receives the *SLA* packet, it saves the location and interest of the sink *S* to its sink information table, and then forwards the *SLA* packet to another neighbor sensor node according to the same rule. This process repeats until the *SLA* packet is eventually received by a sensor node which has forwarded it. The track of the *SLA* packet forms a closed circle as the solid circle shown in Fig.2. Some special cases will be discussed in section Ⅲ.

When a sensor node detects some event and becomes a source node, e.g., node *E* in Fig.2, it initializes a *Sink Location Query*(*SLQ*) message which contains the source node location and the detected event type. A copy of the *SLQ* packet is sent to the *Base Node B* by geographic routing as path $\overline{EB}$ shown in Fig.2, the location of the *Base Node* was gotten during network initialization phase as describe in section 2.1. All the sensor nodes which have forwarded the *SLQ* packet need to save the source node location and the event type in their source information table. The source node *E* also sends a copy of the *SLQ* packet to the farthest neighbor sensor node which *Height* value is 1 bigger than that of itself. When the node receives the *SLQ* packet, it saves the source node location and the event type in its source information table, then the node forwards the *SLQ* packet to the neighbor sensor node which *Height* value is 1 bigger than that of itself. This process stops at the network edge node which received the *SLQ* packet. *A network edge node should never reforward the received the SLQ packet in any case, but it should reforward the received SLA packet as long as it has never forwarded it.* The solid line $\overline{BED}$ in Fig.2 shows the track of the *SLQ* packets.

Observation: *Given a circle and a line, if one end of the line is inside the circle and the other end of the line is outside of the circle, then the circle and the line have at least one crossing point.*

From Fig.2 we can see, one end of the *SLQ* message delivery path $\overline{BED}$ is the *Base Node B* and is inside the *SLA* message deliver circle, the other end of the *SLQ* message delivery path is node *D* and is out side the *SLA* message deliver circle. This mechanism can guarantee that the *SLA* circle and the *SLQ* path $\overline{BED}$ have at least one crossing point *C*. In other words, the sensor node which is located on the crossing point *C* received both *SLQ* and *SLA* packets comes to know the source location, the event type, the sink location, and the sink interest. If the event type matches the sink interest, the sensor node informs the source node about the sink location information as the solid curve line $\overline{CE}$ shown in Fig.2. After getting the sink location, the source node *E* sends data packets to the sink *S* by the geographic routing. This is the basic idea of the proposed sink location service scheme.

III. ANALYSIS

A. Irregular Profile Sensor Network

Most sensor networks have irregular profiles. The proposed protocol can work well in any irregular profile sensor networks. Fig.3 shows an irregular profile sensor network with a hole inside it. There are two source nodes and one sink node in the sensor network. First, the sink node sends a *SLA* packet to announce its location and interest by the mechanism described in section Ⅱ.B. When the sensor node *M* located on the edge of the hole receives the *SLA* packet, since there is no sensor node located on the left side of itself with the same *Height* value, node *M* sends the *SLA* packet to a neighbor node which *Height* value is 1 less then that of itself. When the neighbor node receives the *SLA* packet, it tries to send the *SLA* packet to the sensor node on the left side which *Height* value is closest to the *Height* value encapsulated in the received *SLA* packet. If there is no such a sensor node, it also sends the *SLA* packet to a neighbor node which *Height* is 1 less then that of itself. This process repeats until the *SLA* packet was received by sensor node *N* which has the same *Height* value as that encapsulated in the *SLA* packet. Then the *SLA* packet is continuously forwarded until it was received by the node *P* on the network edge as shown in Fig.3. The subsequent process is similar to the process of bypassing the hole as describe above.

The *SLQ* packet sent by source node may also need to bypass a hole, the hole bypass process of *SLQ* packet can use the perimeter mode [1] of geographic routing scheme. From Fig.3 we can see that, in the irregular profile sensor network, though the *SLA* delivery path is not a real circle, our protocol can guarantee that the *SLA* path and the *SLQ* path have at least one crossing point, e.g., node D_2.

B. *Effects of Base Node*

The *Base Node* has two purposes: one purpose is to initializes the sensor network, the other purpose is to be used as the navigation mark for the *SLQ* messages. For a long term running sensor network, it might happen that the *Base Node* went dead due to the exhaust of energy for having received so many *SLQ* packets. In this case, the *SLQ* packet delivery will stop at the node which is closest to the *Base Node* location. From Fig.2 we can see that the *Base Node* is the center of all sink location announcement circle. So though the *Base Node* went dead, the reliability of the protocol can also be guarantee.

Another problem about the *Base Node* is that where the *Base Node* should be located in the sensor network so that the protocol is most efficient. To analyze this effect, we should consider the perimeter of the *SLA* path circle. Assuming that the distance from a sink to the *Base Node* is r, the perimeter of *SLA* path circle can be calculated as approximate πr^2. To reduce this value, the *Base Node* should be selected as close to the sink node as possible. So before the before network initialization phase, if the location that the sinks may frequently exist is predictively known, the *Base Node* should be selected near this location. Otherwise, the *Base Node* is preferred to be select at the center of the sensor network.

C. *Overhead*

In this scheme, there is no flooding or global grid construction process during sink location announcement and sink location query phase. Only one time flooding is required during network initialization phase. For a long term monitoring oriented sensor network, just one time flooding does not generate significant overhead.

Multiple source nodes and multiple sinks may exist in the sensor network simultaneously. In this case, the *SLA* circle of any sink and the *SLQ* path of any source surely can be guaranteed to have at least one crossing point. Once a sink sends a *SLA* message, all source nodes can get the location of the sink from the node located on corresponding crossing point; once a source sends a *SLQ* message, it can get the location information of all sinks form the node located on the corresponding crossing point.

IV. PERFORMANCE EVALUATIONS

In this section, we evaluate the performance of the sink location service by simulations. First we describe our performance metrics and simulation environments. Then we evaluate the system performance with given environments and parameters. Finally, we show the comparisons between our scheme, flooding, and TTDD[6] protocols.

A. *Simulation Environments and Metrics*

We implemented the proposed sink location service in Network Simulator Qualnet 3.8 and utilized IEEE 802.15.4 as the MAC protocol. The transmission range of sensor nodes is 10*m*. The size of the sensor network is set to 100*100 m^2 where 400 nodes are randomly distributed. The period of each protocol is set to 100s, i.e., in our scheme, source and sink send sink location query and announcement message every 100s; in flooding, sink nodes flooding its own location every 100s; and in TTDD, source nodes construct global grid structure, and sink flooding inside a grid size area every 100s. The grid size of TTDD is set to 30m.

We use three metrics to evaluate the performance of the proposed sink location service. The control overhead is defined as the number of control packets during simulation time. The energy consumption is defined as the total energy consumption of control packets, this metric is based on the number of bytes of all control packet. The sink discovery delay is defined as the time period for the source to find the location of the sink.

B. *Simulation Results*

1) Effect of Simulation Time: In this scenario, one source and one sink are randomly located in the network. We vary the simulation time from 200s to 2000s. Fig.4 shows the control overhead of these three schemes. We can see the control overhead of flooding is remarkably increased than other two schemes, since all sensor nodes need to participate in flooding every time. The overhead of TTDD is lower then flooding, this is because TTDD only requires the nodes located on the edge of grid to construct the global grid periodically. The control overhead of TTDD also includes the local flooding of the sink to find a near dissemination node. In our scheme, source and sink only send the *SLQ* and *SLA* messages along two paths, so the control overhead of our scheme slightly increased with the simulation time. The control overhead of our scheme is higher than flooding and TTDD at the time point 200s, the reason is that the initialization phase of our protocol includes flooding a NI message throughout the whole network. This network initialization overhead occurs only one time during the initialization of the network, it does not relate to the number of source or sink.

Fig.5 shows the energy consumption of the three schemes. We can see this graph is quite similar to Fig.4. This is because the energy consumption is closely related to the number of control packet. The difference is that before the time point of 600s, the energy consumption of our scheme is higher than TTDD and flooding, the reason is that the energy consumption is also related to the size of control packet. In initialization phase of our scheme, the NI packets additionally include a *Height* field than other schemes. In the scenario, we only utilize one source and one sink to evaluate the control and the simulation time is only set to 2000s. In practical sensor networks, the number of source and sink and the running time of the sensor network are far bigger than that of the scenario. So for a long running time sensor network with multiple sources and sinks, the initialization overhead of our scheme is not noteworthy.

2) Evaluation of Sink Discovery Delay: This scenario keep the same density of sensor nodes while varies the network size from 5000m^2 to 50000m^2 to evaluate the average sink discovery delay of the three schemes. From Fig.6 we can see that the average sink discovery of flooding is the shortest one among three schemes, this reason is that, by flooding, the sink location information is directly sent to the source, the packet

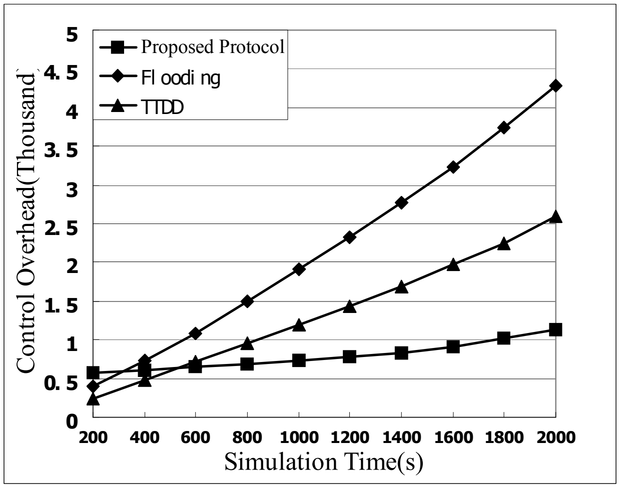

Figure 4. Control overhead with different simulation time.

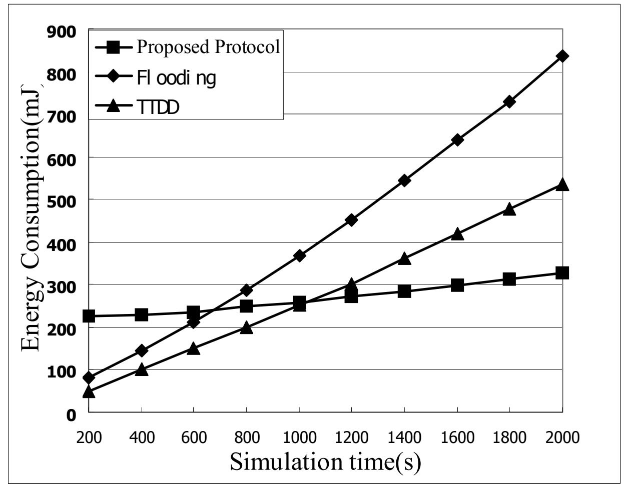

Figure 5. Energy consumption with different simulation time.

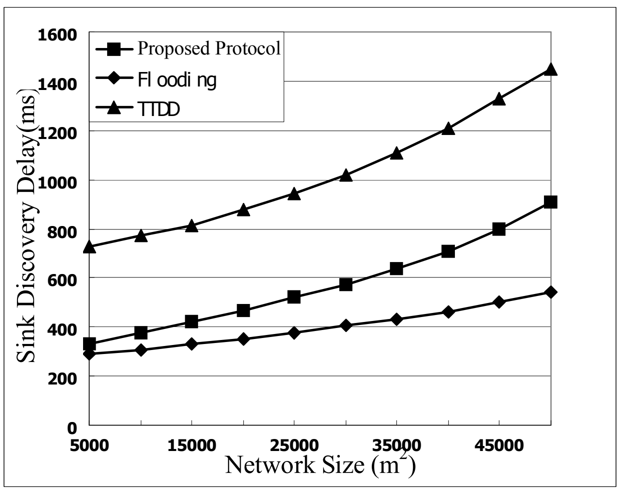

Figure 6. The sink discovery delay with different network size.

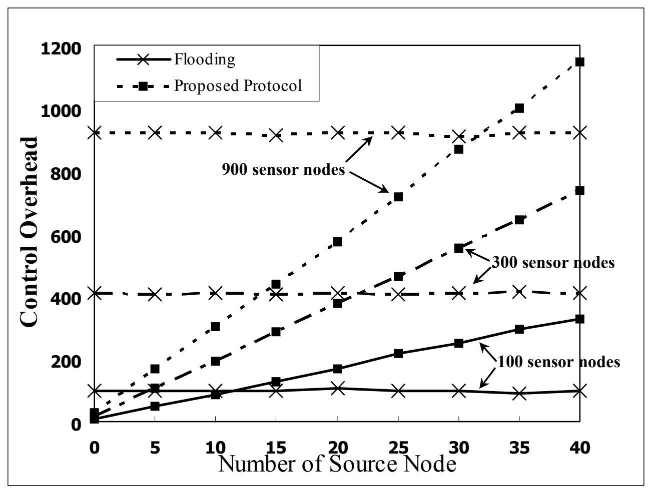

Figure 7. Evaluation of applicability.

delivery path nears a straight line. The sink discovery delay is only related to the distance between the sink and the source. The average sink delivery delay of our scheme is a bit bigger than flooding. This is because that, in our scheme, the sink location is not sent to the source directly by the sink, it needs to be relayed by the crossing point of the sink location query path and the sink location announcement path. The sink location is usually sent to the source along a curvilinear path. The average sink location discovery delay of TTDD is quite longer than our scheme and flooding. The reason is that, in TTDD, source constructs the data announcement grid structure periodically and sink locally floods data query message periodically, these two timers are hardly synchronized, the average sink discover delay of TTDD is mainly due to the difference of these two timers. While in our scheme, the node located on both *SLQ* path and *SLA* path save the location information of the sink or source. This does not require the synchronous of the source and sink. The source can get the location of the sink immediately when the sink exists in the sensor network.

3) Evaluation of applicability: Above analysis and simulation results show that our protocol is significantly superior to other protocols in terms of energy consumption and control overhead. But this protocol does not suit for any condition. For example, in an extreme case, if there is only one sink and all the other sensor nodes are sources, then simple flooding can be the best option for disseminating the sink location. This is because with a single flooding procedure, all the sources will learn the sink location. On the other hand, with the proposed method, every node will send *SLQ* message look for the crossing point. Finally, each crossing node should unicast the information back to the node that sent the *SLQ*. In this case, the overhead of the proposed scheme is higher than flooding. This section tries to find the condition under which our protocol can achieve high performance.

The simulation is done in three scenarios, the number of sensor nodes in each scenario is 100, 400, and 900 respectively. In each scenario, there are only one sink, the number of source nodes varifies form 0 to 40. Each simulation time is 200s. Fig.7 shows the simulation results. The flooding overhead of each scenario is almost a horizontal line. This is because, in flooding, all nodes need to reforward the received *SLA* packet for one time, the flooding overhead has no relation with the number of source node. In our protocol, all source nodes need to send *SLQ* messages, so the control overhead of our protocol is increasd with the number of source nodes. From Fig.7 we can see in the following cases: the case of the number of source nodes is less than 12 in scenario of 100 sensor nodes; the case of if the number of source nodes is less than 22 in scenario of 400 sensor nodes; in the case of the number of source nodes is less than 33 in scenario of 900 sensor nodes, the overhead of our protocol is less than flooding. From the relationship of the number of source node and the number of total sensor nodes in each scenario we can draw a conclusion that if the number of source node is less than the square root of the number of all sensor nodes, our protocol is superior to flooding in terms of control overhead. We should notice that this conclusion is just under the condition that there is only one sink in the sensor network. If there are multiple sinks in the network, the propose protocol is superior to flooding in most case. This result has been proved by many similar numerical and simulation results, though we only describe the above three scenarios here.

V. CONCLUSIONS

In this paper we proposed Circle Path Based Sink Location Service for Geographic Routing in wireless sensor networks. Each senor node gets its own Height value and the location of Base Node during network initialization phase. In this scheme, a source node sends a Sink Location Query (*SLQ*) message to the predefined *Base Node* and sends another *SLQ* message to a node on the edge of the sensor network, thus generating a *SLQ* path; a sink node sends Sink Location Announcement (*SLA*) messages along a circle path, the centre of the circle is the predefined *Base Node*. By this way we can guarantee the *SLQ* and *SLA* paths have at least one crossing point. The node located on the crossing point of the two paths informs the source node about the sink location. Then the source node can send data packets to the sink by geography routing. No flooding or global grid structure is needed for sink location announcement or query. This sink location service is significantly superior to other protocols in terms of energy consumption and control overhead.

REFERENCES

[1] B. Karp, H.T. Kung. "GPSR: Greedy perimeter stateless routing for wireless networks," In Proc. of the 6th Annual Int'l Conf. on Mobile Computing and Networking. Boston: ACM Press, 2000. pp.243-254.

[2] T. He, J.A. Stankovic, C. Lu and T.F. Abdelzaher, "A Spatiotemporal Communication Protocol for Wireless Sensor Networks," IEEE Transactions on Parallel and Distributed Systems, VOL. 16, NO. 10, October 2005, pp.995-1006.

[3] H.S. Kim, T.F. Abdelzaher, and W.H. Kwon, "Minimum-energy asynchronous dissemination to mobile sinks in wireless sensor networks", In Proc. of the 1st ACM international conference on Embedded networked sensor systems, November 2003, pp: 193-204.

[4] Y. Yu, R. Govindan, D. Estrin, "Geographical and Energy-Aware Routing: A Recursive Data Dissemination Protocol for Wireless Sensor Networks," UCLA Computer Science Department Technical Report, UCLA-CSD TR-01-0023,May 2001.

[5] C. Intanagonwiwat, R. Govindan, D. Estrin, "Directed diffusion: A scalable and robust communication paradigm for sensor networks," In Proc. of the 6th Annual Int'l Conf. on Mobile Computing and Networking. Boston: ACM Press, 2000, pp: 56-67.

[6] F. Ye, H. Luo, J. Cheng, S. Lu, L. Zhang, "TTDD: A Two-tier Data Dissemination Model for Large-Scale Wireless Sensor Networks," In Proc. of ACM/IEEE MOBICOM, Sep, 2002. pp: 148-159.

[7] J. Hightower and G. Borriello, "Location Systems for Ubiquitous Computing". IEEE Computer, vol. 34, no. 8, August 2001, pp. 57-66.

[8] A. Savvides and M. B. Strivastava, "Distributed Fine-grained localization in ad-hoc networks", IEEE Transactions of Mobile Computing, 2003.

[9] S. P. Fekete, A. Kroeller, D. Pfisterer, S. Fischer, and C. Buschmann, "Neighborhood-based topology recognition in sensor networks," In Algorithmic Aspects of Wireless Sensor Networks: First International Workshop (ALGOSENSOR), 2004, pp: 123-136.

[10] J.A. Bondy and U.S.R. Murty, "Graph Theory with Applications," (Elsevier North-Holland, 1976).

[11] N. Bulusu, J. Heidemann, and D. Estrin, "GPS-less Low Cost Out Door Localization for Very Small Devices," Tech. rep. 00729, Comp. Sci. Dept., USC, Apr. 2000.