Implicit Location Update Enhanced Reliability for Mobile Sinks in WSNs

Yongbin Yim, Hosung Park, Jeongcheol Lee, Seungmin Oh and Sang-Ha Kim
Department of Computer Engineering
Chungnam National University
220 Gung-dong, Yuseong-gu, Daejeon, 305 764, Republic of Korea
{ybyim, hspark, jclee, smoh}@cclab.cnu.ac.kr and shkim@cnu.ac.kr

***Abstract*—In order to disseminate data to a mobile sink by location-based routing, it is important to provide location information of the sink altering continuously with a source in wireless sensor networks. Fundamentally, it could send directly location information message to a source whenever the sink moves. On the other hand, some schemes without additional cost for location update are proposed recently. The schemes could learn location information by utilizing overhearing of broadcasting nature in wireless transmission environments. Transmission path is turned steadily to the new location at an intermediate node hop by hop per packet along the reverse path. However, if the sink moves frequently while the path is being changed, new location information of the sink exists on the other previous paths rather than on the current path. Therefore, the information might not be propagated to a source securely. Namely, it could not guarantee reachability. In this paper, we propose a novel implicit location service scheme, which guarantees the reachability. With this scheme, we exploit location information of static sensor node as destination information instead of actual location of the dynamic sink. Then, packets are delivered toward one sensor node so the packets could be delivered to the destination. We provide the proof of its reachability and simulation result shows that the proposed scheme has improved than previous works in terms of reliability.**

***Index Terms*—Wireless sensor networks, mobile sink, location service, reliability**

I. Introduction

In wireless sensor networks, mobile sinks have been introduced to consume evenly energy among all sensor nodes for the purpose of prolonging the network lifetime or to be exploited in some applications e.g. battlefield surveillance of soldiers and rescuer who equipped with a personal digital assistants (PDA) for searching survivors [1-2]. Typically, sensor nodes do not have a priori knowledge of the moving speed and direction of the mobile sinks. In order to disseminate data to the sinks, therefore, methods to provide movement information of a mobile sink for a source become important issue.

Geographic routing considered as simple and scalable routing protocol in wireless sensor networks needs several conditions to deliver data to a destination. Location information of destination is one of them. Thus, it could provide movement information by continuous notification of location of a mobile sink. Basic schemes are to deliver location information periodically by utilizing signaling messages [3-5]. However, these schemes demand additional cost to deliver the signaling packets. Recently, energy-efficient schemes for supporting mobile sinks are proposed, which do not require additional cost for location update by utilizing overhearing of broadcasting nature in wireless transmission environments. The nodes on a path could learn location information along the reverse path by hop each data transmission. These schemes could obtain new location without additional cost for location service [6] and turn directly to the new location at intermediate nodes. These approaches are innovative in circumstances that even the location update is a burden under the resource constraints in wireless sensor networks.

If a sink moves slowly, these schemes work well as they intended. Otherwise, if the sink moves fast, data reachability might be not guaranteed. This problem occurs if the sink moves once again while a data delivery path is being converged to the straight-line between a source and the sink. The mobile sink updates its own location to the last node which deliver the data to the sink. However, a last node of the next data delivery path might not be the same node received location update from the sink since data path is turned to the sink at intermediate nodes. In this case, the last node which holds a data could not forward to the new location and then data loss might occur.

In this paper, we propose an implicit location update scheme guaranteeing reachability. With this scheme, we use location of static sensor node as identification of destination, instead of dynamic location of a mobile sink. Therefore, we could guarantee the reachability though the sink moves continuously since a data delivery path is converged to a certain static sensor node. Namely, the sensor node holds the new location and all data are forwarded toward this node. Then, the node could forward to the new location. We provide the proof of its reachability and simulation result shows that the proposed scheme has improved than previous works in terms of reliability.

The rest of this paper is organized as follows. In section II, we give an overview of the implicit signaling for location update and present the reachability problem of this scheme. We

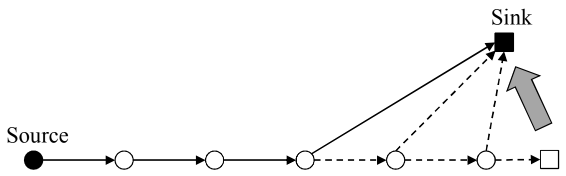

Fig. 1. Basic idea of implicit signaling for location update

describe our scheme to resolve the problem in section III. Section IV provides the proof the reachability guarantee of our scheme and performance evaluation. In section V, we conclude the paper.

II. IMPLICIT SIGNALING FOR LOCATION UPDATE

In this section, we review implicit signaling for location update and discuss the reachability problem.

A. Overview

In existing location-based schemes for supporting mobility, location update has been performed by greedy forwarding from a sink to a source. However, when we consider the resource constraints in wireless sensor networks, even this method is not a little burden for the networks. On the other hand, back-propagation learning method utilizing the broadcasting feature in wireless transmission circumstances is able to deliver location information without additional transmission cost. We categorize them into two types according that whether a network expenses signaling cost for location update or not: explicit signaling and implicit signaling.

With implicit signaling schemes, a node can overhear transmitting packets of neighbors even if the packets are not destined for it. Initially, a sink is obliged to deliver its own location to a source for location update by greedy forwarding only once. If a path is constructed through data delivery to a sink, there must be the last node which sends the data to the sink directly. This node is called *last hop forwarding node*. If the sink exists within the range of the *last hop forwarding node* after the sink moves, the sensor node obtains a location of the sink through beacon messages emitted periodically by the sink. Otherwise, when the sink moves outside of the radio range of the *last hop forwarding node*, the sink detects this situation and sends its new location to the node by greedy forwarding.

In the situation discussed above, the *last hop forwarding node* obtained new location of the sink but the source is not yet aware of the information. Therefore, next data is forwarded toward the previous location. The last hop forwarding node, then, receives the data and forwards it to the sink by resetting to the new location. At this moment, the previous node of the *last hop forwarding node* learns the new location by overhearing the data. A next data delivery path is turned and headed at this previous node for the new location. In the same way, the nodes on the delivery path are able to overhear the new location. The location information is conveyed to the source along the reverse path by back-propagation learning each data transmission as shown in Fig. 1.

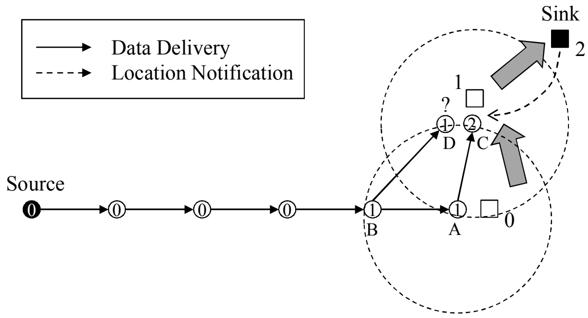

Fig. 2. Reachability problem

B. Network Model and Assumptions

We consider a square sensor field of an area which sensor nodes are randomly distributed. We assume the channel between two nodes is bidirectional, and then the data transmission from one node can be overheard by the other node. A mobile sink sends beacon messages to announce its current location to neighbor sensor nodes. And the sink checks whether it has moved outrange of the last hop forwarding node; if so, informs its current location to the last hop forwarding node by unicasting. We assume that the propagation speed of medium is much faster than the movement speed of a sink. We assume all sensor nodes are static.

C. Reachability Problem

If a sink moves slowly, the implicit signaling scheme above works well without any problems. After the sink moves once and updates to new location, if the sink exists within the radio range of the *last hop forwarding node* until the location is delivered to a source, there is no problem. However, a problem occurs when the sink moves fast, so that the sink leaves the radio range before the source knows the new location. The sink informs new location to one *last hop forwarding node*. However, since data paths are turned to new location at intermediate nodes, the *last hop forwarding node* might be replaced to one of the other nodes. Therefore, though a node holding the new location information is the previous node, this node might not participate in next data transmission since next data path is changed at an intermediate node of the previous path. In this case, the *last hop forwarding node* of the new path is unable to know the new location of the sink. Thus, the last hop forwarding node could not forwarding and the data is lost.

The situation discussed above is presented in Fig. 2. The numbers by the sink denote location. The numbers on the path represent the location of which the corresponding node has currently knowledge. We assume that the source had sent to the location ‘0’ already and the path between the source and the location ‘0’ was built. The sink moves from the location ‘0’ to the location ‘1’. The following data is forwarded to the location ‘1’ via the location ‘0’. After that, the sink moves to the

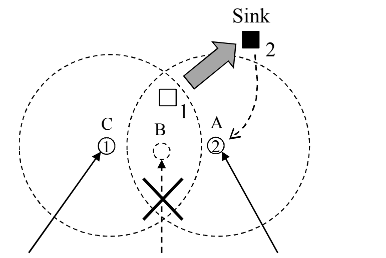

Fig. 3. Another possibility of reachability problem

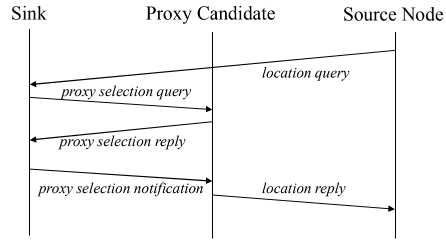

Fig. 4. Proxy selection at initial state

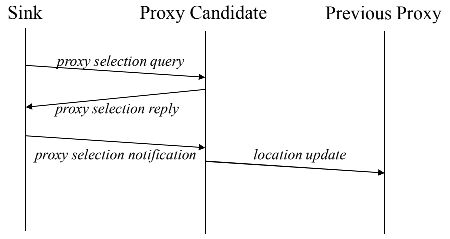

Fig. 5. New proxy selection

location '2' and notifies its own location to the *last hop forwarding node C*. Since the location information '1' is learning by back-propagation through the reverse path, the intermediate node *B* overhears location '1' when node *A* forwards to the location '1'. Next data is forwarded to the location '1' by resetting destination at *B*. However, the data could not be forwarded to the location '2' because node *C* which holds the new location information is not included in the changed path.

Actually, since the two last hop forwarding nodes, *C* and *D*, exist within the radio range of each other, *C* could be aware of the truth that *D* tries to send the data to the destination. So, it seems that this problem is resolved easily as *C* forwards the data instead of *D*. However, we could consider the situation as show in Fig. 3. In the normal case, *A*, *B* and *C* become last hop forwarding node in turn. When *B* transmits to the destination, *A* is able to know and then could forward the packet to the new location. In the same way, when *C* sends the packet to the destination, B could forward to the new location by overhearing. However, in case of that data failure due to other causes occurs during transmission, the problem occurs again. If a data forwarded toward *B* is failed, B does not participate in transmission. Unfortunately, since *A* and *C* exists outside of the radio range each other, *A* could not assist *C*. Therefore, even such try could not resolve completely the reachability problem.

III. Reachability Resolution

As noted earlier, guaranteeing to obtain location information is needed to prevent occurrence of reachability problem due to continuous change of a last hop forwarding node. The problem is that the nodes which deliver data to the sink lastly are separately existed since the destination in the packet header is filled as actual location of the mobile sink. Thus, a node holding a new location of the sink might not participate in transmission of next data. To solve it, we select a sensor node to replace the destination. Then, data are centered to this node and the node passes the data to the sink. In this way, location propagation is conveyed to a source continuously through the reverse path. Therefore, it needs how to select a proxy node. In this section, we describe proxy selection procedure and data forwarding technique through the proxies.

A. Proxy Selection

Proxy selection procedure starts in two situations. First one is when a source detecting an event queries a location of a sink. The sink receives the query, and then elects a proxy. The proxy replies to the query. The rest one is that the sink moves outside of the radio range of the previous proxy node. The sink detects this situation, and then selects a new proxy. Proxy selection procedure performs as follows:

1) The sink broadcasts proxy selection query.

2) Nodes receiving the query responds to the sink instantly.

3) The sink defines the node which sent the reply first. Namely, the sink send a *proxy selection notification* message. Locations of the sink and the previous proxy node (or the source) are included in the message. Only, because no proxy is available at the first time, the location of the source is included.

4) The new proxy receives the *proxy selection notification* message, and sends its own location to the previous proxy node. If the location of the source exists in the message instead of the location of the previous proxy node, the new proxy cognizes that is in initial state. In this case, the proxy notifies its own location when it receives the query from the source.

Fig. 4 and Fig. 5 show the procedure described above.

B. Data Forwarding

When a source detecting an event tries to send data to a sink, the source obtains the location of the destination by location service. As discussed above, the location of the destination is the position of a proxy node. The source fills the destination field in the packet header with this location. The packet is delivered to the designated destination through intermediate nodes. If the sink exists within the radio range of the designated proxy, the proxy node could deliver the packet to the sink. Otherwise, if the sink deviates from the radio range of designated proxy and a new proxy has been selected, since the designated proxy is aware of the new proxy, the designated proxy forwards continuously by resetting the destination field in the packet to the new location. This process is repeated until the proxy that is available to communicate directly with the sink receives the packet as show in Fig. 6.

Since location information is delivered by hop through back-propagation learning each transmission, data is transmitted to a new location by resetting the destination at an intermediate node. However, if location information has no sequence, loop might occur since it is possible that some node overhears older information after recent information. Therefore, the proposed scheme prevents inversion learning by marking order

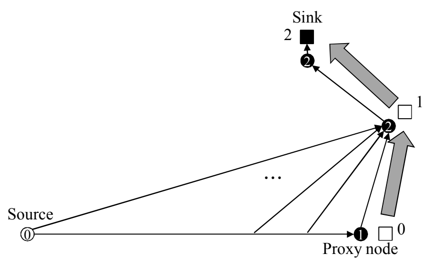

Fig. 6. Data forwarding via proxy nodes

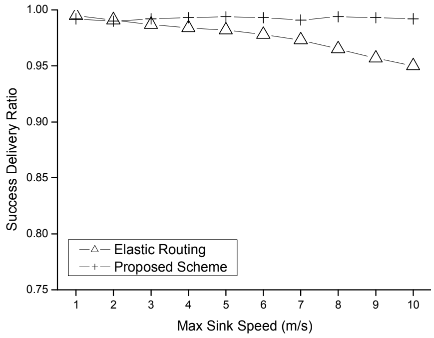

Fig. 7. Success delivery ratio impacted by sink speed

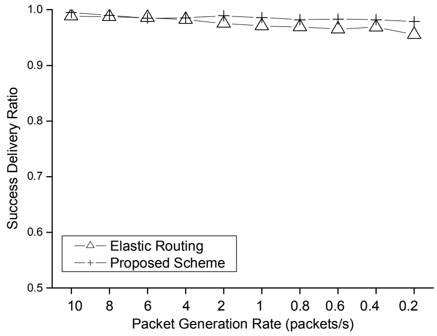

Fig. 8. Success delivery ratio impacted by packet generation rate

information such as sequence number or time stamp.

IV. Analysis and Evaluation

We prove the path reachability of our scheme though the following mathematical theorems.

A. Reachability Guarantee

Based on the network model and assumptions discussed in Section II, we prove that reachability is guaranteed by introducing the method which traces the mobile sink through proxy nodes.

Theorem 1. A packet is surely able to reach a sink if the protocol exploits a proxy based footprint-chaining that utilizes the location of a proxy node instead of the location of the sink.

Proof. We prove the theorem by induction.

Let *P(n)* be the proposition that a packet could be delivered through n proxy nodes for the positive integers n.

- Basis: If there is only one proxy node (when $n = 1$), a source could deliver data to the proxy node directly by initial location service [7, 8]. Because $n = 1$, the proxy node is the last proxy node. The sink is always within the range of the last proxy node according to the proposed scheme, so the packet on the proxy node is able to reach to the sink.
- Inductive step: For the inductive hypothesis, we assume *P(k)* is true. To complete the inductive step we must show that the proposition *P(k)* $\rightarrow$ *P(k+1)* is true. The *k*th proxy node is able to aware the position of the *(k+1)*th proxy node by location update message of *(k+1)*th proxy node. A packet on the *k*th proxy node could be reached to the *(k+1)*th proxy node. This shows that if the inductive hypothesis *P(k)* is true, then *P(k+1)* must also be true. This completes the inductive argument.

Theorem 2. With implicit signaling schemes, although destination information in a packet might be changed at intermediate nodes between proxy nodes, the reachability is also guaranteed.

Proof. Location information learned by intermediate nodes, but no proxy node, is among the locations of the proxy nodes, 1 to n. Therefore, data is delivered to a proxy node, so the reachability is guaranteed by *theorem 1*.

B. Simulation Results

We compare the performance of our proposed scheme with that of Elastic routing [6] that is a representative implicit signaling scheme in WSNs. We implemented three protocols in Network Simulator Qualnet 4.0 [10]. Sensor nodes follow the specification of MICA2 [11] and their transmission range is about 15m. IEEE 802.11b was used as the MAC layer protocol. The size of the sensor network is set to 250m × 250m where 2000 nodes are randomly distributed. For all simulations, we use one source-sink pair for performance evaluation. We use the following metrics for performance analysis and evaluations: the success delivery ratio is defined as the ratio of the number of data packet successfully received by the sink to the number of data packets generated by the source. The control overhead is defined as the total number of control packets. The average energy consumption is defined as average consumption of twenty times of transmission. Transmitting and receiving power consumption rates of the sensors are 21mW and 15mW, respectively. The group moved following the *random waypoint* mobility model [9]. Default speed of the sink is set to 3m/s. Both schemes exploit XYLS [7] for initial location discovery of the mobile sink.

Fig. 7 shows success delivery ratio for the speed of the sink. If the speed increases, the success delivery ratio of Elastic routing decreased due to missing new location information at a last hop forwarding node. The success delivery ratio of the proposed scheme is almost unchanged because the data is delivered through proxy nodes. The destination information is static, so that the ratio is not affected the speed of the mobile sink.

Fig. 8 shows success delivery ratio for the packet generation rate. The success delivery ratio of Elastic routing is decreased according to the packet generation rate decreasing. It is because lower packet generated rate leads to infrequent location propagation of the mobile sink. Thus, each time the sink moves out of the radio range of the last hop forwarding node, the data packets sent by the last hop forwarding node during the moment are all dropped. The success delivery ratio of the proposed scheme is independent of packet generation

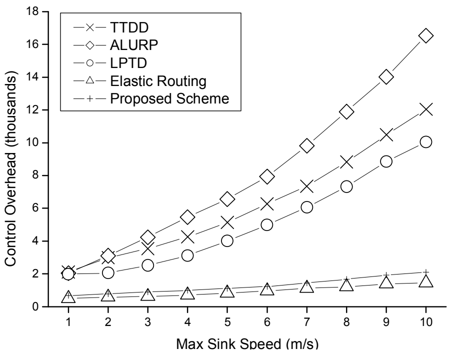

Fig. 9. Control overhead impacted by sink speed

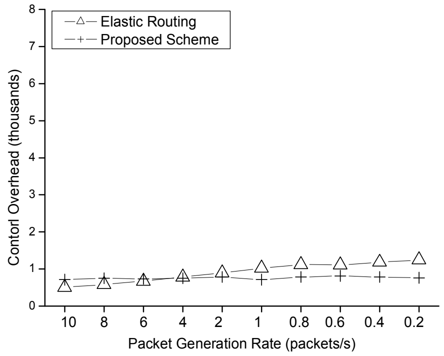

Fig. 10. Control overhead impacted by packet generation rate

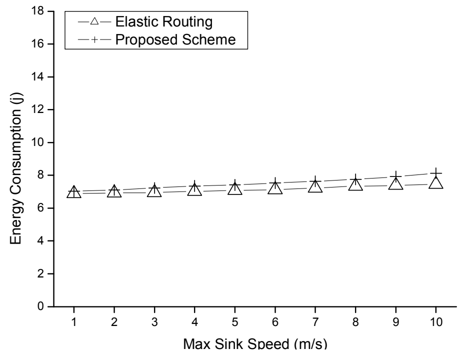

Fig. 11. Energy consumption impacted by sink speed

rate. In the proposed scheme, the success delivery ratio is not affected almost by the packet generation rate. When the sink moves out of the range of the last hop forwarding node, the sink elects new proxy node. So, packets are delivered robustly via the proxy nodes.

Fig. 9 shows the control overhead according to the speed of the mobile sink. The faster the speed rises, the more the control overhead of the proposed scheme increases slightly than that of Elastic routing. If the sink moves fast, it means that the sink deviates from the range of the last hop forwarding node. Consequently, it leads more proxy nodes election. However, compared with other explicit signaling location services, the proposed scheme has still less control overhead.

Fig. 10 shows the control overhead for the packet generation rate. With a lower packet generation rate, the sink may move out of the radio range of the last hop forwarding node with a higher probability during the interval between two data transmissions in Elastic routing, thus the sink needs to frequently inform its location to the last hop forwarding node. This makes the control overhead grow. On the other hand, the control overhead in the proposed scheme is independent of the packet generation rate. Regardless of the packet generation rate, when the sink moves out of the range, it selects new proxy node. So, the control overhead in the proposed scheme is not affected by the packet generation rate.

Fig. 11 shows the average energy consumption for the speed of the sink. The metric of energy consumption is closely related to the total transmission. In the proposed scheme, if the speed grows, more proxy node selection is needed. Thus, due to exchanging proxy selection messages, the proposed scheme consumes energy a little more than Elastic routing. However, within practical speed of the sink, the average energy consumption is not significant.

V. Conclusion

In this paper, we propose a novel scheme for guaranteeing reachability of implicit signaling for a mobile sink in wireless sensor networks. The implicit signaling schemes do not require additional cost for location update since the schemes utilize overhearing feature, so that these approaches are attractive. However, if the mobile sink moves fast, the destination information which is location of the sink might invalid since new location information could not be propagated due to changing the last hop forwarding node holding the location information. We pose this as the reachability problem. To solve it, our scheme exploits location of a proxy node as destination information instead of location of the mobile sink and presented a proof of guaranteeing reachability. Thus, although the sink moves fast, data is delivered safely to the sink in the end since the destination is exists always.

We conducted experiments to evaluate the performance of our proposed scheme. Our main findings are that the reachability problem is resolved and yet we could keep the energy-efficiency.

References

[1] J. Al-karaki, and A. Kamal, "Routing techniques in wireless sensor networks : a survey," *IEEE Trans. on Wireless Communications*, Vol. 11, Iss. 6, pp. 6-28, 2004.

[2] S. Gandham, M. Dawande, R. Prakash, and S. Venkatesan, "Energy efficient schemes for wireless sensor networks with multiple mobile base stations," in *Proc. IEEE GLOBECOM*, pp. 377-381, 2003.

[3] G. Wang, T. Wang, W. Jia, M. Guo, and J. Li, "Adaptive location updates for mobile sinks in wireless sensor networks," *J. Supercomput.*, Vol. 47, Iss. 2, pp. 127-145, 2009.

[4] J. Lee, W. Yu, and X. Fu, "Energy-efficient target detection in sensor networks using line proxies," *Int. J. Commun. Syst.*, Vol. 21, Iss. 3, pp. 251-275, 2008.

[5] F. Ye, H. Luo, J. Cheng, S. Lu, and L. Zhang, "A two-tier data dissemination model for large-scale wireless sensor networks," *ACM MOBICOM*, pp. 148-159, 2002.

[6] F. Yu, S. Park, E. Lee and S. Kim, "Elastic routing: a novel geographic routing for mobile sinks in wireless sensor networks," *IET Communications*, Vol. 4, Iss. 6, pp. 716-727, 2010.

[7] I. Stojmenovic, D. Liu, and X. Jia, "A Scalable Quorum-based Location Service in Ad Hoc and Sensor Networks," *International Journal of Communication Networks and Distributed Systems*, Vol. 1, No. 1, pp. 71-94, 2008.

[8] J. Li, J. Jannotti, D. Couto, D. Karger, and R. Morris, "A scalable location service for geographic ad hoc routing," in *Proc. ACM MOBICOM*, pp. 120-130, 2000.

[9] J. Broch, D.A. Maltz, D.B. Johnson, Y.-C. Hu, and J.G. Jetcheva, "A performance comparison of multihop wireless ad hoc network routing protocols," in *ACM/IEEE MOBICOM*, pp. 85-97, 1998.

[10] Scalable Network Technologies, Qualnet, [online] available: http://www.scalable-networks.com.

[11] J. Hill and D. Culler, "Mica: a wireless platform for deeply embedded networks," *IEEE Micro*, Vol. 22, Iss. 6, pp. 12-24, Nov./Dec. 2002.