A SPATIOTEMPORAL DATA DISSEMINATION PROTOCOL FOR SLOWLY-VARYING MOBILE SINKS IN WIRELESS SENSOR NETWORKS

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Abstract: In wireless sensor networks (WSNs), previous real-time data dissemination schemes for stationary sinks exploits the spatiotemporal approach, which utilizes the delivery speed based on the fixed distance between a source and a static sink to fulfil the desired time deadline. This approach cannot be directly applied to a mobile sink since the distance can be varied depending on its movement. That is, the delivery speed cannot be determined without knowing the distance between a source and a mobile sink. It must be the hardest problem for all intermediate sensors to know the current location update of the mobile sink and control their transmission speeds. We focus on the real-time data dissemination for a slowly varying mobile sink compared to the transmission speed, which may be the most common case. By the slowly varying constraint, the movable area of a mobile sink can be determined by the two factors: its speed and the distance between a source and its initial location. In this paper, we propose a real-time data dissemination scheme for a mobile sink by utilizing the movable area concept. Simulation results show that the proposed scheme provides a high success ratio in terms of the guarantee of real-time requirement.

1 INTRODUCTION

Many applications in WSNs, such as battlefield surveillance and earthquake response systems, are tailored to interact with fast changing events and required to gather the event data in an application desired time deadline (He, 2005) (Felemban, 2006). The existing protocols for the real-time applications in WSNs mainly exploit the *spatiotemporal approach* which forwards data at the delivery speed. The desired delivery speed is calculated by dividing end-to-end distance by the time deadline. In the protocols, each node on the data dissemination route selects a node as its next-hop node which is nearer to the sink and provides a better relay speed. The relay speed means the advance in distance to each next node dividing by the delay to forward a packet to the each next node. End-to-end real-time data dissemination is achieved by maintaining the desired delivery speed from sources to the sink. However, the protocols typically assume sinks are stationary.

Recently, sink mobility has been receiving attentions from the researchers of WSNs (Li, 2009) (Akyildiz, 2002). Since the mobile sinks are able to move within the sensor field, source nodes could not accurately know the location of the mobile sink because of continuous movement of the sink. For mobile sinks, the spatiotemporal approach cannot be directly applied since the distance could be varied depending on the movement of mobile sinks. That is, the delivery speed could not be determined without knowing the intermediate sensors to know the current location update of the mobile sink and control their transmission speed. Moreover, since the time overhead for sink location update is occurred frequently, it might not fulfill the time deadline. Since the end-to-end distance may be longer, the initially calculated delivery speed could not guarantee the real-time data dissemination. Hence, the real-time data dissemination needs to adapt a new approach for the distance between the source and the mobile sink. We focus on the real-time protocol only for a slowly varying mobile sink compared to the transmission speed, which may be the most common case. By the slowly varying constraint, the movable area of a mobile sink can be determined by the two factors: its speed and the distance between a source and its initial location.

In this paper, we propose a real-time data dissemination protocol for slow varying mobile

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sinks based on a virtual region for movable area of the sink. The protocol utilizes the movable area concept. The virtual region of movable area provides the maximum distance of the slow varying mobile sink. Through the virtual region, the source node could determine the data delivery speed for the spatiotemporal approach. Simulation results show that the proposed protocol provides a high success ratio in terms of the guarantee of real-time requirement.

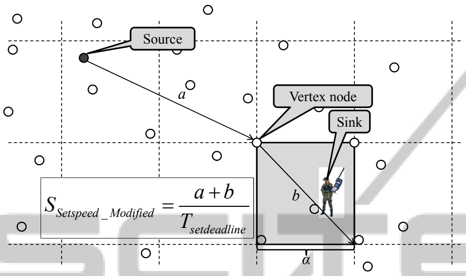

Figure 1: Real-time data dissemination for mobile sink with modified spatiotemporal approach.

2 PROPOSED PROTOCOL

In this section, we propose and describe a Region-based Real-time Data Dissemination (RRDD) scheme to support sink mobility of real-time data dissemination.

2.1 Assumptions

RRDD relies on several assumptions that are explicitly and implicitly exploited in other studies about real-time routing (He, 2005) (Felemban, 2006) (Li, 2009) and many geographic unicast routing schemes (Akyildiz, 2002) (Hamida, 2008) (Karp, 2000) as follows.

- Once a phenomenon appears, the sensor nodes surrounding the phenomenon collectively gather information and one of them becomes the source to generate data of the phenomenon (Akyildiz, 2002) (Hamida, 2008). And the mobile sinks require knowing where the sources locate.
- The source nodes that generate event data could be provided the location of sink by one of the sink location services (Li, 2000) (Park, 2009).
- For the geographic unicasting routing, which is one of the stateless routing method, each sensor node is aware of its own location after deployment by receiving Global Positioning System (GPS) signals (Karp, 2000) or using some localization techniques (Bulusu, 2000).
- All the nodes and the sinks have a priori knowledge about the size and the center point (x_c, y_c) of the sensor field.

2.2 Spatiotemporal Approach

While in multi-hop wireless sensor networks, since communication is physically bounded, the end-to-end delay depends not only on single hop delay (temporal), but also on the distance a packet travels (spatial). The spatiotemporal approach for real-time data disseminations utilizes a data delivery speed. The approach calculates the data delivery speed by dividing the end-to-end distance by the desired time deadline. Each node on the dissemination route selects a node as its next-hop node if it is nearer to the sink and provides a better relay speed than the desired delivery speed. The relay speed means the advance in distance to each next node dividing by the delay to forward a packet to the node. The end-to-end real-time data dissemination is achieved by maintaining the desired delivery speed.

2.3 Modified Spatiotemporal Data Dissemination Approach

In the proposed protocol, the data dissemination procedure consists of two steps: 1) forwarding the data from the source to one of the vertex nodes registered by the sink, and 2) forwarding from the vertex node to the sink. The time deadline $T_{setdeadline}$ depends on applications in WSNs.

To reduce data detour, the vertex node, which locates between the source and the sink, is selected as a data relay node. The source node selects a vertex node (x_{cp}, y_{cp}) as follows:

$$\begin{aligned} (x_s - x_{cp}) \times (x_{cp} - x_{src}) \geq 0 \\ (y_s - y_{cp}) \times (y_{cp} - y_{src}) \geq 0 \end{aligned} \quad (1)$$

where (x_s, y_s) and (x_{src}, y_{src}) is the location of the sink and the source node, respectively. We define T_{f1} and T_{f2} as the time of forwarding data from the source to the selected vertex node, and the time of forwarding from the vertex node to the sink, respectively. $T_{setdeadline}$ should be larger than the total sum of both T_{f1} and T_{f2}. The distance of forwarding data is the total of the distance from the source node to the vertex node and the distance between the vertex node and the sink node. However, since the mobile sink moves continuously, we could not estimate the distance between the vertex node and the sink. The length of the longest straight line from a crossing point within a coarse-grained grid is $\sqrt{2}\alpha$. From the nature of wireless sensor networks, since the time for data propagation is proportional to the distance for itself (Park, 2009), the following equation is established. The source node could calculate the modified delivery speed $S_{setspeed\_modified}$, which is the desired delivery speed from itself to the vertex node, with the calculated time T_{fl} as follows:

$$S_{setspeed\_modified} = \frac{\sqrt{2}\alpha + d(src, cp)}{T_{SetDeadline}} \quad (2)$$

A vertex node, which receives data from the source, acts as the relay node for the virtual region. The node also stores the current location information of the sink to relay the data from the source to the sink. However, since the time passes from the registration time, the sink may not be on the registered point. Therefore, before the new periodical update of sink location, data from the source should be sent to the area the sink will be expected to locate. For this, we are able to exploit flooding data into a whole cell to disseminate them. But it wastes a lot of energy since all nodes in the region have to participate in the communication mode. The width of a cell of the grid is V_S x $T_{setdeadline}$. During the $T_{setdeadline}$, the sink could move out of the registered cell of the grid but within the cell and at most its adjacent cells. The vertex node concurrently sends the data to 9 cell leaders. If some of the adjacent grid cells are not belonged to the virtual region, the sink prepare a new region through the current location. Through this process, though the sink moves out of the virtual region, the data could be continuously disseminated to the sink. In the cell of the grid, the data are propagated to the sink by limited flooding. The total of the distance from a vertex node to the leader of grid and the distance of data flooding is equal to or less than $\sqrt{2}\alpha$. Consequently, the data delivery in the grid cell is achieved.

3 PERFORMANCE EVALUATION

3.1 Simulation Environments and Metric for Performance Evaluation

In this section, we compare the performances of RRDD with that of other real-time data dissemination protocol, SPEED (He, 2005), which is the most popular real-time protocol in WSNs. However, since SPEED does not consider mobility support, we add footprint chaining method to SPEED. The protocols are implemented in Qualnet (Scalable, SITE). The simulation network space consists of 2,500 sensors randomly deployed in 500m × 500m area. The radio range of sensor is 10m. A source node generates 30 byte-packets with interval 0.5s. The simulation time is 50 seconds and the sink has random way mobility model. Transmitting and receiving power consumption rates are 21mW and 15mW, respectively (Hill, 2002). All results are the average values of 100 times of simulation.

3.2 Simulation Results

Figure 2 shows the values of TDSR in the proposed scheme and SPEED in accordance of the sink speed. We vary the speed from 0m/s (stationary) to 35m/s. The width of the virtual region is 100m and the end-to-end distance between the source and the sink is fixed at 200m. Since SPEED calculates the desired delivery speed with the initial location of the sink, the possibility of data dissemination on the time deadline is decreased. And as the speed of the sink moves faster and the distance due to foot-print chaining becomes longer, the possibility is decreased much more. However, in the proposed scheme, since the source node calculates the delivery speed considering the region to be expected for the sink to locate and sends its data with the desired delivery speed, the value of TDSR in the scheme is higher than that in SPEED though the speed of the sink increases.

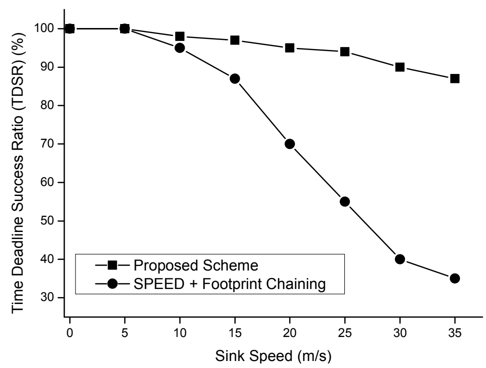

Figure 2: Time deadmine success ratio according to sink speed.

The values of TDSR of the RRDD and the SPEED according to the end-to-end distance are presented in fig. 3. The longer the end-to-end distance becomes, the larger the hop count of data path is. The speed of the mobile sink is fixed to 15m/s and the width of the virtual region is 100m. As described above, since SPEED does not consider the increase of the end-to-end distance, the value of TDSR is decreased as the distance increases. But since the proposed scheme considers both the distance and the speed of sink, it has higher value of TDSR than SPEED.

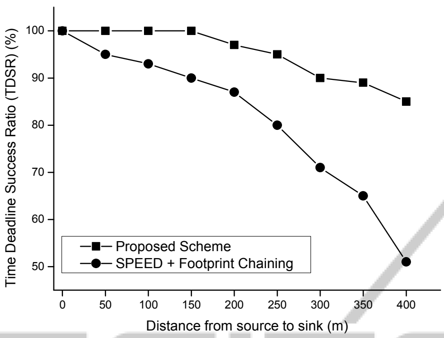

Figure 3: Time deadline success ratio according to end-to-end distance.

Figure 4 indicates the TDSR of the proposed scheme according to both the end-to-end distance and the virtual region size. We also vary the region size from 60m to 140m. The speed of the mobile sink is fixed to 20m/s and the time deadline is 1.0s. If the grid size is smaller, the frequent updates are need. Since the mobile sink could move out of the grid region during data dissemination due to small grid size, the TDSR is decreased.

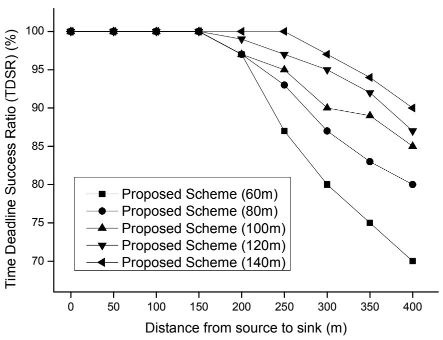

Figure 4: Time deadline success ratio according to both sink speed and grid size.

4 CONCLUSIONS

In this paper, we propose a new real-time data dissemination scheme for mobile sinks in wireless sensor networks. The existing schemes for real-time service to stationary sinks exploits the spatiotemporal approach which forwards data at the delivery speed calculated through the fixed distance between a source and a static sink and the desired time deadline. However, in case of mobile sinks, since the distance between the source and the sink is dynamically changed, it is difficult to adapt the approach. So, our scheme considers the virtual region to be expected for the mobile sink to locate in, and calculates the desired delivery speed based on the region. The proposed scheme exploits the virtual region and grid based infrastructure. Simulation results show that the proposed scheme has better performance than the existing scheme in terms of guaranteeing the real-time dissemination.

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