Opportunistic Spatiotemporal Routing in Wireless Sensor Networks

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Abstract: We propose an opportunistic spatiotemporal data dissemination protocol in order to solve the transmission failure problem in error-prone WSNs. Retransmission is well-known for recovery of transmission failure; however, this may cause the severe time delay possibly to violate the real-time requirement. To solve the problem, our protocol exploits both broadcasting nature and temporal opportunity concept. In a radio-range of a sensor node, there may be multiple neighbor nodes to satisfy the real-time requirement. By broadcasting property, all neighbors can receive a data from a node, and only each satisfying neighbor decides its relay toward the destination by using temporal selection function. The temporal function is related to the tolerable time period to be able to satisfy the real-time requirement. By giving the priority to the node with smaller tolerable time, we have more opportunities to forward toward the destination. That is, even if a node with a long tolerable time waits for the longer period of time, it still has a chance to forward with the real-time requirement. In summary, the proposed protocol attains the high reliability and real-time requirement by removing data retransmission and multiple opportunities with temporal consideration.

1 INTRODUCTION

Wireless Sensor Networks (WSNs) gather their objective information from a large number of sensor nodes with limited communication and computing power. The sensor nodes generate reporting data about events and forward them to sinks via multi-hop communication. Many applications in WSNs, such as battlefield surveillance and earthquake response systems, should be tailored to interact with fast changing events and required to gather the event data in an application desired time deadline. The geographical real-time data dissemination protocols typically try to maintain a desired delivery speed across the sensor network. The protocols choose the nodes which have the relay speed faster than the desired delivery speed. However, the protocols focus the data dissemination within the desired time deadline and do not consider the reliable communication.

Several routing protocols have been developed for reliable communication due to the limitation of sensor nodes in error-prone WSNs. Some reliable data dissemination schemes (Akyildiz, 2002) in WSNs are based on the retransmission in which either the source node or the relay nodes are responsible for detecting packet loss and retransmitting the lost packet for recovering error. The schemes choose only a sensor node as a next-hop node and transmit data packets to the selected node. But, in case of transmission failure to the selected node, the schemes should require data retransmission to the same neighbor or possibly another neighbour in order to increase reliability. Other reliable data dissemination protocols (Felemban, 2006) exploit the multipath routing. The protocols make the multiple copies of data packets and forward them through multiple paths. The data redundancy could provide the high reliable communication.

However, the reliable data dissemination protocols still have some problems. The retransmission protocols are well-known for recovering the transmission failure; however, they may cause the severe time delay possibly to violate the real-time requirement. And the multipath routing protocols only increase data delivery ratio but could not assure that all data packet arrive at the destination node. It also wastes an amount of network energy, shortens the network lifetime and leads to traffic congestion.

In this paper, we propose an opportunistic spatiotemporal data dissemination protocol in order to increase the reliability by using broadcasting

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nature and temporal opportunity concept. By broadcasting property, all the neighbors can receive a data from a node. Among the neighbors, there may be multiple sensor nodes which could fulfil the real-time requirement, and each neighbour among the nodes decides its relay toward the destination by using temporal selection function. The temporal function is related to the remaining time, which stands for the tolerable time period to be able to satisfy the real-time requirement. By giving the priority to the node with smaller remaining time, we have more opportunities to forward toward the destination. That is, even if a node with a long remaining time waits for the longer period of time, it still has a chance to forward with the real-time requirement. In summary, the proposed protocol attains the high reliability and real-time requirement by removing data retransmission and multiple opportunities with temporal consideration. Simulation results show that the proposed protocol is superior to the existing protocols in terms of real-time data dissemination.

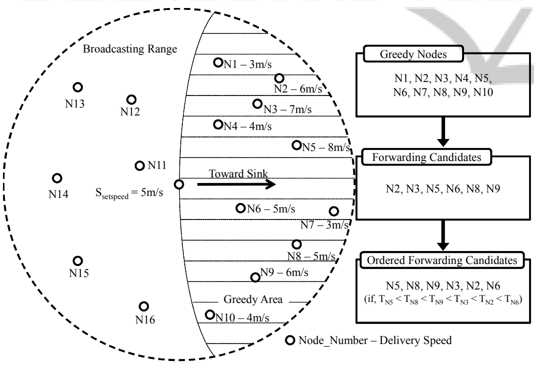

Figure 1: Next-hop candidate decision.

2 NETWORK MODEL

Our proposed protocol relies on several assumptions that are explicitly and implicitly exploited in other studies about real-time routing (He, 2005) (Felemban, 2006) and many geographic unicasting routing protocols (Akyildiz, 2002) as follows.

- A large number of homogeneous sensor nodes are deployed over a vast field, and then the nodes self-organize an ad-hoc network. Long distance data delivery is performed through multi-hop communication manner.
- 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.
- The source nodes that generate event data could be provided the location of sink by one of the sink location services.
- 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 or using some localization techniques.
- Every sensor node has its own neighbor node table including the coordinates and the estimated delay of its neighbors by periodic beacon signaling.

The existing protocols (He, 2005); (Felemban, 2006) for real-time data dissemination mainly exploit the spatiotemporal approach in order to deliver data from a source to a static sink within a desired time deadline $T_{setdeadline}$. While in multi-hop wireless sensor network, 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). For this, source nodes initially calculate a desired delivery speed $S_{setspeed}$ with the time deadline and the end-to-end distance *d(source, sink)* from the source to the sink as follows:

$$S_{setspeed} = \frac{D(source, sink)}{T_{setdeadline}}$$

In the protocols, each node on the dissemination route selects a node as its next-hop node which is nearer to the sink and provides a better relay speed than the desired delivery speed $S_{setspeed}$. 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. The end-to-end real-time data dissemination is achieved by maintaining the desired delivery speed from sources to the sink. However, if the sink moves around, the distance between them changes dynamically, so that the end-to-end distance and the data delivery speed $S_{setspeed}$ should be also altered. But the re-calculation of the distance and the delivery speed per every hops let the sensor nodes have an amount of computing overhead.

3 OPPORTUNISTIC REAL-TIME ROUTING PROTOCOL (ORRP)

For routing, sender nodes have the two following tasks: next-hop selection and data forwarding. The sender nodes select one node as the next-hop node among its 1-hop neighbor nodes. Then, the nodes include the address or geographical coordinates of the next-hop node into data packets for the next-hop node to receive the packets. In the proposed protocol, the selection of the next-hop node is determined by the next-hop candidates. The next-hop candidates could receive the data packets from its previous sender. The proposed protocol gives the opportunity for data packet forwarding to receiver nodes that receive the data packets successfully. Before the data forwarding, each nodes obtain the information of its own neighbor nodes by beacon signaling. The information includes the location of neighbor nodes and the processing time for a data packet, namely, hop delay. Similar to other real-time data dissemination protocols, each node keeps a neighbor table to store the information. By the information, the each forwarding nodes select the candidate node as its next-hop node which are closer to the destination (sink) and which delay speed is faster than desired speed Ssetspeed. In the proposed protocol, sender nodes include the list of candidates into the packet header. The data packets are broadcasted by the sender node. The neighbor nodes which receive the data packets determine whether itself will forward the data packets or not, with the information of the packets.

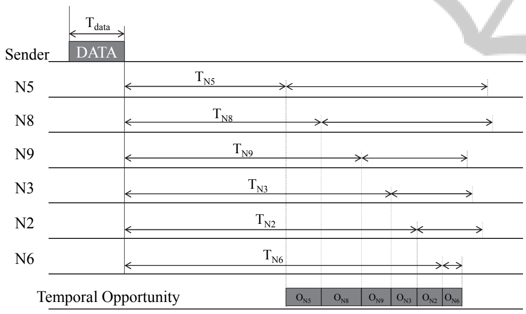

Figure 2: Temporal opportunity.

Before forwarding data packets, sender nodes (including source nodes) select the candidates that will receive the data packets. Neighbor node set NS_i includes the multiple neighbor nodes within the radio range of the node *i*. As described above, the node *i* stores the coordinates and single hop delay of the members in NS_i. The node divides NS_i with the forwarding candidate set and the non-forwarding candidate set. For the forwarding candidate set, the proposed protocol chooses some nodes which are closer than the sender node toward the destination. Based on the set, the sender node calculates the relay speed RS_{Cn} of each node n_{Cn} with the following equation:

$$RS_{Cn} =$$
$$(dist(n_i, dest) - dist(n_{Cn}, dest)) / hopdelay_i^{Cn}$$

where *dist(n, dest)* is the distance between the node *n* and the *destination* and $hopdelay_{Cn^i}$ is the single hop delay from the node *i* to the node *Cn*. In the forwarding candidate set, only the neighbor nodes, which have the larger relay speed than the desired delivery speed, are included. The forwarding candidate set list and the single hop delay of the forwarding candidates are sent with the data packets to the candidates. The forwarding candidate set in the data packet is sorted with the single hop delay in order to preferentially select the node which has the shortest hop delay. As shown in Fig. 1, the sorted list could provide the opportunity to forward data packets to maximum candidates. The candidates could relay the data packets after the sum of transmission delay T_{data} and their own single hop delay T_{ni} due to the queueing delay of the sensor nodes. And the data packets could not be forwarded after the per-hop desired time deadline since the data packet is out-dated after that time. The per-hop desired time $T_{hop\text{-}deadline}$ between node *i* and node *Cn* is: $(dist(n_i,dest)\text{-}dist(n_{Cn},dest))/\ S_{setspeed}$. As a result, the data packets should be forwarded in the time from T_{ni} to $T_{hop\text{-}deadline}$. The nodes have the data forwarding opportunity in order of the single hop delay. By the temporal opportunity, the i^{th} node could forward data packets in $T_i \sim T_{i+1}$.

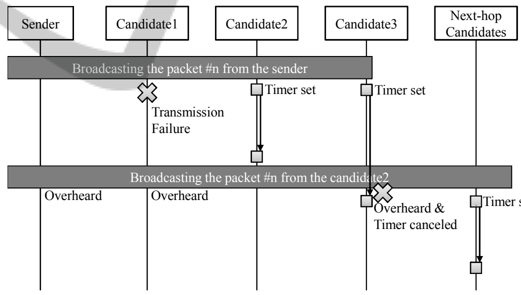

Figure 3: Time diagram for next-hop decision.

The sensor nodes, which receive data packets and forwarding candidate list from their upstream node, decide whether they will relay the data packets or not. First, nodes check that the node is included in the forwarding candidate list. If the node is one of the candidates, the node sets its timer with its single hop delay. As shown in Fig. 2 and 3, all candidates start their timers. The node C1 needs not to start the timer since C1 does not receive the data packets successfully. The candidates overhear the same packet transmission of the other candidates because the multiple candidates could concurrently send the packet. It might cause the transmission failure due to the collision. The overheard node cancels its own timer and discards the data packet. If the timer of a candidate is released with no overheard transmission, the node starts the next-hop forwarding for the data packet. The opportunistic routing has a constraint that the nodes in forwarding candidate set should be able to hear from each other. Otherwise, the packet duplication would occur. For prohibiting from the packet duplication, the previous node sends a control message for timer cancel. Because only the previous sender node could send the message to all candidates including not-overheard candidates.

4 PERFORMANCE EVALUATION

We have implemented the proposed protocol in the Qualnet network simulator. We compare the proposed protocol with SPEED (He, 2005) and MMSPEED (Felemban, 2006), the most popular real-time protocols. The simulation network space consists of 500 sensor nodes uniformly deployed in a 500m X 500m square area. The radio range of each sensor nodes is about 50m. The source node generates 30 byte-data packets with interval 0.05s. The simulation time is 50s and the required reliability is 85%. The results are the average value of 100 times of simulation.

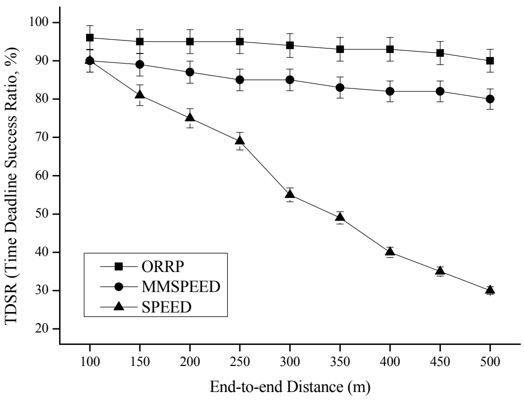

Figure 4: Time diagram for next-hop decision.

Figure 4 and 5 show the TDSR impacted by the end-to-end distance and the number of sensor nodes. In SPEED, the longer the end-to-end distance, the lower the time deadline success ratio. It is because that SPEED does not consider the packet reliability and a number of data packets are lost in SPEED. The TDSR of MMSPEED is similar to the desired reliability since MMSPEED branches the multiple paths when the calculated reliability is under the desired reliability. The multiple path increases the time deadline success ratio. The proposed protocol results in the high TDSR since the per-hop reliability is proportional to the opportunity to forward data. The number of sensor nodes means the node density in the sensor field. The larger the node density is, the larger the number of 1-hop neighbor nodes is. As the number of sensor nodes increases, the TDSR is converged to almost 95%.

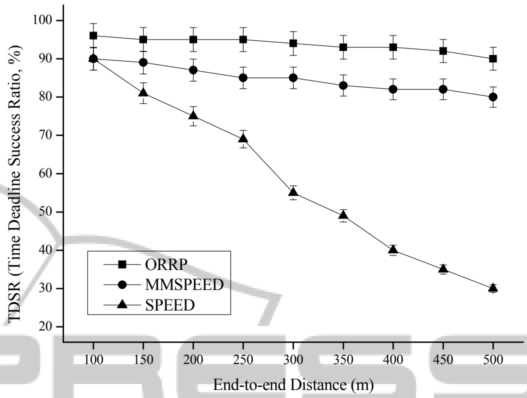

Figure 5: Time diagram for next-hop decision.

5 CONCLUSIONS

In this paper, we propose an opportunistic routing protocol for real-time data in order to increase the reliability of transmission. Since our protocol gives the opportunities to forward data to multiple neighbor nodes, using the nature of broadcasting and the temporal opportunity distribution, the protocol could increase the reliability of real-time data.

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