RELIABLE AND REAL-TIME DATA DISSEMINATION
IN WIRELESS SENSOR NETWORKS

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ABSTRACT

In wireless sensor networks, both real time and reliable transmission are the big research challenge. But current approaches in these research fields have not been well explored because there are so many restrictions on respective sensor node. In this paper, we propose a new reliable real time routing protocol in sensor networks. For real time delivery, we introduce a time-based forwarding scheme in wireless sensor networks. In addition, reliable transmission is accomplished by multiple transmissions based on link quality in such a distributed way. Finally, simulation results are presented to demonstrate the proposed scheme meets real time and reliable transmission in wireless sensor networks.

INTRODUCTION

Most of applications are mainly categorized according to strict requirements on them in wireless sensor networks. For example, a specific sensing data is assumed to be delivered within bounded time period from source to destination, called as deadline. The time-sensitive information delivered after deadline is not longer available at all. So, all layers should cooperate with each other to meet this requirement. In the point of network layer, routing protocol should be designed to find out the path where end-to-end delay is expected to be shorter than deadline.

Another considerable requirement in a sensor networks is reliability which is defined as how to guarantee data delivery to destination successfully. Due to harsh environments such as node itself and unstable wireless communications, packet drop is so natural. Hence, it is critical requirement to reduce the number of lost packets in wireless sensor networks. Despite of the fact that it is not easy to guarantee above one feature, mission-critical applications are increasingly demanded to meet two requirements together.

To meet above requirements, some literatures[1-9] have been published but they partially cover the requirements. First of all, as to real-time transmission, two kinds of approaches have been proposed. One is real time scheduling that is based on priority scheduling because queuing delay is the biggest component in end-to-end delay. The good example is VMS (Velocity Monotonic Scheduling)[3]. In VMS, a node takes real distance and time till expiration into account when it comes to assign priority dynamically. VMS may be implemented by multiple priority based queue. The other is real time routing, which is designed to find out the path meeting end-to-end requirement. The SPEED [4] is well-known protocol for real time routing in sensor networks. In SPEED, a node expects the delay between itself and neighboring node. With this information, a neighbor node is chosen for real-time forwarding. VMS and SPEED adapt the similar scheme in that geographic information is used to obtain velocity. Other approaches include Velocity-based Forwarding[5] and Real-time Power-Aware Routing[6].

For reliability, multiple path routing and recovery schemes have been recently proposed. These methods are not novel approach but modified according to nodes’ several constraints and properties of sensor networks. The example includes Braided Multipath Routing[7] and PSFQ (Pump Slowly Fetch Quickly)[8]. The former maintains multiple paths for robust communications. This approach is different from typical multipath routing scheme in that weak disjoint property is adapted for dense wireless sensor networks. The PSFQ is designed to recover packet loss in the
middle of transmission. For fast recovery, a packet is divided as several small segments. By retransmitting lost segments on an intermediate node, high reliability can be achieved. Well-known other protocol for reliable transmission is ESRT (Event-to-Sink Reliable Transport) [9].

Even though existing schemes have been proposed to cover one of requirements, as far as the author knows there is no well-explored scheme to include two requirements together. In this paper, in order to meet above two requirements, we proposed R2TP (Reliable Real-Time Protocol) in wireless sensor networks. In R2TP, a node decides data forwarding based on time information to destination. In addition, every intermediate node decides how many packets are duplicated on it according to link quality to meet high delivery ratio. If the link quality is measured to have good condition enough to achieve high reliability, a data is transmitted without duplications to save battery and communication resource. On the contrary, link quality is not enough to guarantee data delivery, a node makes packets duplicated and transmits them along separate multiple paths by choosing many respective neighbor nodes for each transmission. This is possible because multiple paths are easily found and established in densely deployed sensor networks.

The rest of this paper is organized as follows. In section II, we describe the proposed scheme with major two phases, path setup and data forwarding. Also, new metric and algorithm are explained in the same section. Simulation results are explained in section III. Finally, we make a conclusion in section IV.

PROPOSED SCHEME: R2TP

In R2TP, data dissemination from each sensor to sink is accomplished according to two major parts such as path establishment and setup, and data forwarding as illustrated in Figure 1.

A. Path Setup

In R2TP, path establishment is initiated by a sink node. A sink node broadcasts its interests to whole networks. During this phase, interest message containing current sending time and delivery time requirement specified in an application is newly defined.

When an intermediate node receives this message, it gets current time and calculates how much time is elapsed by subtract current time and sending time. If the elapsed time is greater than delivery time requirement, it doesn’t broadcast this message any more because it cannot guarantee data delivery in bounded time. Otherwise, it records previous node’s address, elapsed time on a table and sends back acknowledgement message. With above procedure, each sensor node keeps the next node, which is able to deliver data to a sink within bounded deadline. According to above procedure, path is established toward a sink. The established path is newly maintained by another broadcast.

In this case, elapsed time can be varied based on network environment such as congestion.

To adapt variation on time from a sink, each node calculates and maintains table to consider it. To achieve this, at the \( p^b \) interval, delay to sink on node \( i \) is defined as equation (1) where \( D_{i,j}^p \) does delay between node \( i \) and \( j \) measured by \( p^b \) broadcast message. Both \( w_1 \) and \( w_2 \) are weight factor.

\[
D = \left( w_1 \times D_{i,sink}^{p-1} + w_2 \times D_{i,sink}^p \right) / (w_1 + w_2) \tag{1}
\]

B. Data Forwarding

When an intermediate sensor node receives data packet, data forwarding is done by three steps in Figure 1. Step 1 is to check whether entry in table is created or not during path setup phase. In step 2, a node decides whether multiple transmissions are needed or not according to newly defined link quality. Finally, when multiple transmissions are required on this node, another decision for how many duplications should be made. We explain each step in this section.

STEP 1: selecting next hop

When a sensor node detects event matched with an interest, it searches cache table whether it has entry for next node to the destination or not. If one entry is found, it sends data to next node. In case of no entry searched, it sends this message with current time and trial number to neighbor node,
which records the shortest delay. When next node receives this message, it repeats above procedures until decreased trial number is not equal to zero or adequate entries are found. When multiple entries are found in cache table on a node, entry for delivery at this time is chosen by hash function with current time that provides as unique seed value. This is because if an entry is repeatedly chosen, it causes node’s rapid battery drain along the path. This problem is the biggest concern in SPEED, which is well-known real-time data dissemination protocol in sensor networks. In SPEED, the best route is selected to forward data so it accelerates quick energy consumption on a node if there is no congestion. For reliability, our approach is to utilize multipaths. However, general multipath approaches have some drawbacks. First, it has big burden to discover disjoint paths between source and destination. Second, additional control overhead is caused to maintain each path. To solve above problem, our approach is that a node decides how many packets will be forwarded according to link quality between neighboring nodes. If the area is regarded to be covered by good communications environments with good link quality, data transmission is accomplished along one path in order to minimize the energy consumption on nodes along the path. Otherwise, delivery failure is covered by multiple transmissions. For reliability, our approach is to utilize multipaths. However, general multipath approaches have some drawbacks. First, it has big burden to discover disjoint paths between source and destination. Second, additional control overhead is caused to maintain each path. To solve above problem, our approach is that a node decides how many packets will be forwarded according to link quality between neighboring nodes. If the area is regarded to be covered by good communications environments with good link quality, data transmission is accomplished along one path in order to minimize the energy consumption on nodes along the path. Otherwise, delivery failure is covered by multiple transmissions.

Figure 2. Example of Reliable Transmission

After a node finds entries after searching the next node in a cache table, it checks link quality between them. If this link is considered to be under bad quality, a node makes duplications in order to transmit data along separate path. To prevent duplicated forwarding, a node maintains the sequence number of data.

In Figure 2, S1 sends data in a form of unicast to S2. When S2 receive this packet, it finds out the next nodes, S2, S3 and S4. And then, S2 selects one of them evenly for the next hop. In this example, we assume S5 is chosen. Because the link between S2 and S5 is not good link quality, S2 increases the number of next nodes for reliability. So, S2 sends multiple data to them. S5 works similarly. On the other hand, both S3 and S4 send one data packet. S8 receives data from S6 and S7.

STEP 2: link quality

According to link quality, reliability and resource efficiency are determined in R2TP. So, it is very important to measure link quality properly. Generally, link quality is measured and defined by successful packet delivery ratio. Link quality between node A and B is defined as equation (2).

\[
\text{Link Quality (A, B)} = \frac{\text{packet delivery ratio (A,B)}}{1} \quad (2)
\]

\[
\text{packet delivery ratio (A,B)} = \frac{\text{total number of receiving packets}}{\text{total number of sending packets}}
\]

STEP 3: the number of multiple transmission

Even though multiple transmission controls the reliability, however it is closely related to resource consumption. So, it is desirable to decide how many packets are duplicated. For this, link quality is reliability requirement. In order to simplify, we use packet delivery ratio used in equation (1).

In case packet delivery ratio between a node and chosen neighboring node by hash index function is smaller than requirement, more nodes are selected until sum of packet delivery ratio is larger than requirement. For this one, ordered greedy scheme is introduce. For ordered greedy algorithm, all links are sorted according to packet delivery ratio. In this algorithm, if a link is selected, its packet delivery ratio is compared to requirement. If it is smaller than predetermined value, it continues selecting next one, which has smaller packet delivery ratio until requirement is met by sum of packet delivery ratio of links. Whenever a node decides the number of duplication, a starting point is changed. So, well-distributed data transmission is naturally achieved.

Figure 3. Greedy algorithm

In Figure 3, we use hash function to index entry in table. This hash index is designated as starting point. For example, if the requirement of packet delivery ratio is 0.95, node 1 cannot meet requirement. Another node 2 is also included because sum of two nodes’ delivery ratio is greater than requirement and node 2 is next one in order.
SIMULATION RESULT

In this section, we evaluate performance of R2TP for each performance parameter. The objective of simulation is to find the critical operational problems of R2TP as well as compare performance with existing protocols. We describe simulation results for each algorithm and then compare R2TP with existing protocols in terms of packet delivery ratio within deadline, packet delivery ratio for reliability, and time till partition. In this section, we compare R2TP with other existing protocol SPEED.

- Packet delivery ratio within deadline is defined as how many packets are delivered to a sink within deadline.
- Packet delivery ratio for reliability is defined as how many packets are delivered to each group member, which is supposed to receive all data packets from source.
- Time till partition is defined as elapsed time a network is partition due to node’s complete battery drain at the first time.

Simulation Model and Environment

For diverse simulations, our simulation code was implemented around GloMoSim simulator [10]. The simulation parameter and each protocols variable are described as follows. Our simulation modeled a network of 100 nodes placed randomly within a 1000 * 1000 area. Radio propagation range for each node was 50 meters and channel capacity was 256kbit/sec. Each simulation is executed for 20000 seconds of simulation time. Multiple runs with different seed numbers were conducted for each scenario and collected data was averaged over those runs. Nodes are uniformly placed. General CSMA is used as MAC protocols and two-ray model is for propagation models. The application for this simulation is SURGE, which reports the sensing information at the rate of predetermined period. For this simulation, a sensor node is supposed to transmit information every four second.

Result Analysis

Figure 4 shows packet delivery ratio within deadline. As you can see in Figure 3, R2TP shows better performance than SPEED. As the number of nodes increases, the bigger difference is measured. This is because more congestion cases happen in SPEED. In SPEED, there is no congestion aware scheme. On the contrary, path between sensor and sink is periodically re-established in R2TP with current and last elapsed time. Moreover, the same path is selected whenever the calculated speed is faster than other even though there are multiple paths meeting deadline. To prevent this feature, path is chosen randomly in R2TP so congestion is early prevented and diverse paths are selected.

Figure 4. Packet delivery ratio within deadline

When it comes to successful packet delivery ratio, R2TP shows higher performance than SPEED. The comparison is shown in Figure 5. As to packet delivery ratio in R2TP, it is worthwhile to mention relationship between packet delivery ratio with the number of nodes. As the number of nodes increase, multiple paths are easily found out and established. So, packets are transmitted along separate paths so sink can receive many duplicated packets. This contributes the high packet delivery ratio. Another negative feature is the control overhead and congestion. In order to measure link quality and maintain path periodically, it increases the number of hello and control message. These control messages cause packet loss. The other feature is congestion. Even though R2TP prevents congestion in an ordered greedy algorithm, congestion cannot be avoided. Consequently, above features are well-balanced so the packet delivery ratio is maintained within acceptable range. In SPEED, there is no reliable scheme to recover and control lost packets. Hence, the congestion on special link becomes worse as the number of nodes increases because the best link is continually chosen by multiple paths.

Another weak feature in SPEED is illustrated in Figure 6. In order to denote value, we introduce the elapsed time from the beginnings of simulation until at least one part is not covered by sensor nodes in Figure 6. Because of battery drain on nodes, information around any specific area is not available. If this case happens first, we record this time. Based on this value, the Y axis is represented by per-
percentage against total simulation time. The battery model in this simulation is as follows. The battery starts with a fixed capacity and each transaction that a node does (transmission, reception of a packet, carrier sensing), an amount is deducted from the remaining capacity. For simplicity, the total capacity to begin with is assigned small value and the units are mA-hour. For current simulation, we adapt MICA2 as hardware type.

Since both schemes don’t have energy aware property, they suffer from uncontrolled energy consumption. Due to multiple transmission and large number of control message, battery drain on R2TP is quicker than one on SPEED. Despite of this fact, life time shows the different shapes. Whole networks are covered by sensor nodes for longer time on R2TP than SPEED in Figure 6. This is mainly because battery drain is well-balanced in R2TP while the same path is chosen in SPEED.

CONCLUSION

Similar to typical networks, real time and reliability transmission becomes one of great research challenges. Even though some schemes have been proposed to achieve these requirements, some deficits remain. To solve these problems, a new protocol called as R2TP is proposed. For R2TP, both new path setup and data forwarding schemes are developed.

For path setup phase, forwarding entry based on elapsed time to sink is used to guarantee transmission within deadline. In addition, reliable transmission via multiple paths is made. Through simulation, we demonstrate the performance on R2TP in terms of packet delivery ratio and lifetime.

Reference