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Improving MintRoute Protocol at Different Scenarios

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Abstract: Outstanding features such as low-rate and short-range wireless radio communication on a small device often hamper high reliability in wireless sensor networks. Despite of these constraints, high reliability becomes one of the essential requirements since it is highly demanded by more and more network services. To meet this requirement, various approaches have been proposed in each layer. Among those, MintRoute is a well-known network layer approach that develops a new metric based on link quality for selecting path towards the sink. By choosing a link with the highest measured value, the possibility to transmit packets without error becomes high. However, there are still several issues to be mentioned during operations. In this paper, we focus on network stability in MintRoute. We analyze different features which make MintRoute unstable and propose the revised algorithm by developing new metric together with adjusting parent selection procedure at different scenarios. Simulation results and analysis validate the suitability of stabilized time to enhance the reliability of communication.

Keywords: MintRoute, Stability, Performance Evaluation

1 Introduction

Although Wireless Sensor Networks (WSN)[1] research is initially driven by military applications such as battle field surveillance and enemy tracking. WSN has recently become more and more popular by carrying out environmental monitoring, mobile target tracking, smart space, and ubiquitous computing. A wireless sensor network can be deployed anywhere without infrastructure like ad hoc networks. Thus, WSN becomes more attractive in other risk-associated applications, such as habitat monitoring and environmental observation by increasing the fault-tolerance and robustness of the system. In such networks, users specify the data they want to send as simple SQL (Structured Query Language) like queries that use predications rather than specific addresses.

The good example of application includes Great Duck Island (GDI) system. This system is developed by UCB/Intel Research Laboratory in order to monitor the behavior of storm petrel [2] on Great Duck Island, Maine, August 2002. Thirty two motes were placed at area of interest for monitoring. Those motes, grouped into sensor patches, transmit sensor reading to a gateway, which is responsible for forwarding the data from the sensor patch to a remote base station through a local transmit network. The base station then provides data logging and replicates the data every fifteen minutes to a Postgress database in Berkeley over satellite link. Remote and local users interact with the sensor network in two different ways. Remote users can access the replica database server in Berkeley, where a small PDA-size device can be used to perform local interactions such as adjusting the sampling rates, power management parameters etc. As we discussed, there are additional research works for Environment Observation and Forecasting System (EOFS), Health Applications, and Structure Health Monitoring (SHM) System.

Despite of above comparative applicability in real world, the most noteworthy drawback of the wireless sensor network is caused by node itself in that each sensor node is operated in a low-rate and short range wireless communication. In addition to limitation on wireless medium, since a node has the low computing power and capability, high complexity of algorithm and protocol should be avoided. Due to these regular weaknesses, it is very hard to guarantee reliability, which implies messages sent by a sender should be delivered to the destination without errors during transmission. Moreover, since the reliability is generally influenced by many factors such as channel loss, interference, bandwidth limitation, traffic peaks, and node resource constraints, complementary scheme needs to be implemented in each layer in order to cover unreliable and resource-constrained wireless sensor networks.

To solve above problems, several fundamental mechanisms and tunable parameters have been proposed. These approaches have applied to validate existing schemes of wireless sensor network by modifying some procedures. They include rate control, scheduling policy, drop policy, explicit notification, acknowledgements, MAC backoff, and next-hop selection. In particular, PSFQ (Plum slowly fetch quickly) [3] and RMST (Reliable multi-segment transport) mechanism [4] have been proposed to guarantee the reliability in transport layer. In PSFQ, a segment is divided into smaller multiple segments while providing sufficient time to detect a loss over intermediate node. RMST includes several reliability schemes based on ARQ and NACK. On the other hand, schemes like ARC (Adaptive rate control) [5] and ESRT (Event-to-sink reliable transport) [6] were proposed to control congestion in transport layer. In ESRT, the domain for reliability is scattering into four regions, which consist of uncongested-sub-threshold, uncongested-over threshold, congested-over threshold, and congested-sub threshold. According to current region, a sink provides feedback to the source directly in order to control congestion.

In network layer, several routing protocols have been proposed to address the reliability problem. HHR (Hybrid reliable routing) technique [7] was designed to construct hierarchical network architecture rather than flat under the assumption that the cluster architecture can guarantee reliability by communicating between cluster headers having more power and higher data rate on wireless communication radio. Another network layer routing protocol, RLRR (receiver-oriented load-balancing and reliable routing) [8] proposed to achieve both load balancing and reliability for large scale wireless sensor networks Besides these two HHR and RLRR, other approaches proposed to develop routing protocol, which make use of new metric suitable for reliability in wireless sensor networks. The authors in [9] proposed a potential-based routing scheme to find routes with high delivery ratio. The basic idea of the potential-based routing is to define a 'potential' at a node. Forwarding traffic is achieved by simply choosing a neighbor with the highest potential. Similar to potential routing, MintRoute protocol proposed in [10] using similar approach for estimating link quality, i.e. to estimate link quality, average packet reception ratio is measured with periodic beacon message. In addition, MintRoute uses a simple function, which sums up link cost and parent cost. The parent cost indicates the parent node's reachability to sink node or base station.

Even though MintRoute is regarded to reveal the acceptable performance at certain scenarios, several research works have mentioned potential operational issues and proposed novel solutions [11-13]. First, the authors in [11] addressed the security problem in MintRoute by proposing scheme to prevent link quality attacks by a malicious node. In this work, a novel "sequence number gap trick" to test for and detect the presence of a malicious attacker has been proposed and evaluated through ns-2 simulator. Moreover, the authors in [12] addressed how to use supervised learning techniques to make informed decisions in the context of wireless sensor networks. Also, they investigated the design space of both offline learning and online learning and use link quality estimation as a case study to evaluate their effectiveness. Another modified MintRoute protocol in [13] proposed an enhanced version of mint called PA-mint. A transmission power control interface is added to network layer in PA-mint. When routing performance of the current network is not satisfied, PA-mint monotonically increases the transmission power via the interface we added.

However, several important features such as operation by beacon messages and parent selection by qualified value make MintRoute protocol unstable. Despite of this fact, previous research works for MintRoute does not mention it and does not explore the impact on performance yet. Thus, the performance of MintRoute is worthwhile to be studied and surveyed in depth. In this paper, we analyze the main reason of instability of MintRoute and their impact on various topology as well as scenarios. Based on this, we propose a new method to reduce stabilized time, which is the defined time required to stabilize the networks. As well, we conduct simulation study for MintRoute in above scenarios and provide the analysis and discussion.

The rest of the paper is organized as follows. In section 2, we briefly explain MintRoute protocol operation. In following section 3, our solution followed by the analysis of instability will be presented. In section 4, simulation results are presented and analyzed. Finally, conclusion and further work are described.

2 Overview of MintRoute

MintRoute builds tree based topology toward the sink. As compared to the shortest hop routing protocol, each node measures the link quality toward the sink. Among multiple links, a neighbor node having the highest value over the link is assigned as parent node. In order to estimate link quality in MintRoute, periodical beacon message and packet reception ratio are employed. In addition, for smoothing computed value, exponential moving average method is also introduced. For parent selection, MintRoute follows three major steps. First, it discovers neighbors and estimates the link quality through broadcasting beacon messages periodically. This packet carries sequence number to detect if any packet is lost, when the time period is over. PRi,j (packet reception ratio) for the link between node i and j is given in equation (2.1). In equation (2.1), Packets_Rcv represents the number of packets received correctly. Also, Packets_Exp represents the number of packets expected that means the number of packets actually sent. The time interval for beacon is set to t. Thus, parent selection procedure is accomplished every t seconds.

$$PR_{i,j}(t-1,t) = \frac{Packets\_Rcv \text{ in } t}{MAX(Packets\_Exp \text{ in } t, Packets\_Rcv \text{ in } t)} \quad (2.1)$$

By applying exponential moving average method, link cost is computed in equation (2.2), where α is ranged from 0 to 1. Based on the value from equation (2.2), a node with the largest LRi,j(t) is selected as parent of node i as shown in equation (2.3), where NS represents set of neighbors within the transmission range

$$L_{i,j}(t) = \alpha \times PR_{i,j}(0,t-1) + (1-\alpha) \times PR_{i,j}(t-1,t) \quad (2.2)$$

$$P_i = MAX(\underset{j \in NS}{\arg\max}\{L_{i,j}(t)\}, L_{i,P_i}(t)) \quad (2.3)$$

When a node finishes computing, the resulting value is compared with cost on a parent in equation (2.3). If a new cost is greater than parent node's cost, a new parent is chosen and then packets are transmitted along this new link. Otherwise, current node serves parent continuously.

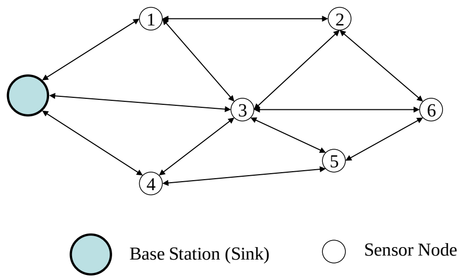

Figure 2.1: Neighbor discovery : step 1

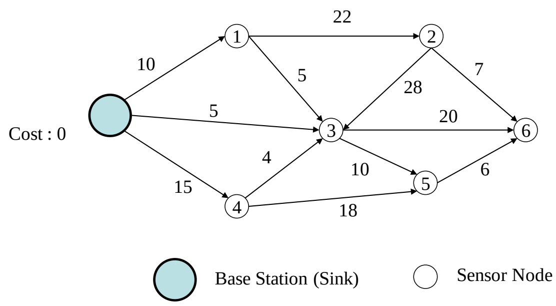

Figure 2.2: Cost estimation : step 2

Based on above procedure, Figure 2.1 and Figure 2.2 show how MintRoute estimates cost for each link. In Figure 2.1, each node uses beacon message to discover the neighbor and collect the link quality information. After finding neighbors, the link cost is set as shown in Figure 2.2. In next step, parent selection algorithm is accomplished with this computed value. Furthermore, Table 1.1 shows the cost of each node when parent selection phase is completely done. For example, a node 6 sends the packet to the sink along the path 6-5-3-0, because the parent of node 5 is set to node 3. Through this procedure, each link maintains a reliable link toward the sink periodically.

Table 1.1: Cost for parent selection

Node ID	Cost	Parent
1	10	0
2	32	1
3	5	0
4	9	3
5	15	3
6	21	5

Causes of Instability. Based on basic operation of MintRoute, instability is mostly caused by link selection procedure and data collection for measurement over the link. Current MintRoute takes a long time to get stable value from the initial network time. At the starting time, since each node has little information for the link, parent changes are made frequently. Another reason as explained before, if a new computed value is greater than the previous one, then a new parent is selected. Even though exponential moving average method makes the smooth value, this procedure is also potential cause of instability in MintRoute. The last reason is backward parent selection problem. Unlike the initial operation, a node can select the backward parent towards the sink according to the computed value in equation (2.2). This backward forwarding decreases the reliability as well as makes the network unstable. These three main procedures make the MintRoute unstable.

3 Proposed Scheme

To handle the mentioned problems in above section, our approach to revise MintRoute includes development of new metric for stability and modification of parent selection algorithm. In detailed, both parent changes based on the counter and preventing backward parent selection procedures are newly introduced. Procedures for parent selection are explained in following algorithm.

Algorithm: Parent Selection

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1. For all forward link j on node i
   compute $L_{i,j}(t) = \gamma * \mathrm{PR}_{i,j}(t\text{-}1, t)$ (2.4)
   $\gamma = \dfrac{m}{\sigma}$
   where $m = \sum RSS_i \times W_i / \sum W_i$
   σ = standard deviation

2. For all forward link j on node i
   if $-\psi < \mathrm{MAX}(L_{i,j}(t)) - L_{i,j}(t\text{-}1) < \psi$
   counter_j++

   else
   $P_i = argmax\{ L_{i,j}(t)\}$
   $j \in$ NS

3. if *counter_j* $> \zeta$
   $P_i = j$
   counter_j=0

STEP 1: In order to complement the decision based on packet delivery ratio, we include RSS (Received Signal Strength) variable to choose stable link in physical communication environment when we calculate link quality. This is mainly because packet delivery ratio is mostly affected by status on physical link in wireless sensor networks. Since RSS is mostly affected by physical environment such as barrier, stability of this value is good environmental indicator for better link. With RSS, we give higher weight to the node when it receives packets at stabilized power level, which means small variation. A new link cost with RSS is defined in equation (2.4). In addition to this new value for stability, unlike the original MintRoute, only forwarding links toward the sink are concerned to prevent backward parent. Forward links are distinguished by comparing Level Identifier value that is taken as the shortest hop distance from the sink. This value is chosen as the value that computed at the first link selection procedure. If Level Identifier value of node *i* is greater than node *j*, then *j* may select *i* as a parent. Otherwise, a node j excludes the link to *i* in parent selection phase.

STEP 2: In this step, a new computed maximum $L_{i,j}(t)$ value is compared with current value. If difference between two values is bounded in acceptable range, a current parent node is maintained to prevent frequent parent change. Instead, a counter variable increases for each link. Otherwise, if the difference is above the maximum value, a new parent node is selected as the node with the largest $L_{i,j}(t)$ value.

STEP 3: When a counter value exceeds threshold as well as this situation continues, we replace the old parent with a new one according to $L_{i,j}(t)$. Also, the variable is set to 0, repeatedly.

Another cause of instability is brought by not giving enough measuring opportunity on the link. At the initial phase in MintRoute, each node computes its $L_{i,j}(t)$, however this value is determined by little exchanged information. Thus, the parent is likely to be changed very frequently. To solve above situation, a node explicitly includes $L_{i,j}(t)$ in computation when the total number of processing packets exceed the minimum number in the proposed scheme. In order to achieve this procedure, STEP 2 in parent selection algorithm should be changed as follows. Instead of changing current parent, counter value increases.

else if (num_packets > min_threshold)
$P_i = \mathrm{argmax}\{ L_{i,j}(t)\}$
$j \in$ NS
else
counter_j++

4 Performance Evaluation

In this section, we conduct simulation to derive the problem of MintRoute as well as validate the performance of revised one. For diverse simulations, Qualnet simulator [14] is used. The simulation parameter and each protocol variable are described as follows. We modeled a network of nodes placed within an area of 350m * 350 meters, randomly or uniformly. The range of radio propagation for each node was 50 meters and channel capacity was 256kbit/sec. Each simulation is executed for 2000 seconds. Multiple runs with different seed numbers were conducted for each scenario and collected data was averaged over those runs. General CSMA (Carrier Sense Multiple Access) is used for MAC(Medium Access Control) protocols and a two-ray model is executed for propagation models. The application for this simulation is SURGE, which reports the sensing information at the rate of predetermined period, 50 msec. For original MintRoute, α in equation (2.2) is set to 0.6 and interval for beacon message is 1 second.

Time for Stable Networks. First simulation is to compare how much time is taken to make network stable from the starting time. We compare revised and original MintRoute as a function of number of nodes in Figure 4.1 and Figure 4.2 at the different topology. The time for stability is measured by the elapsed time until the number of node changing parent becomes less than 20% among total number of parent selection phase. In Figure 4.1, we can see that revised algorithm has shorter time for stability than original one on random topology. In addition, as the number of nodes increases, elapsed time becomes shorter and shorter. On the contrary, original MintRoute has little impact on number of nodes. In revised algorithm, the more nodes we deploy more accurate measurement between nodes we get. Thus, revised algorithm has better performance than original in dense deployment. Also, since the higher LRi,j(t) value with small number of processed packets does not affect the parent selection in revised one, time for stability in revised algorithm become shorter than original one. As compared to Figure 4.1, Figure 4.2 shows the significant reduce difference between two schemes where nodes are placed on uniform topology. Also, the same pattern as the Figure 4.1 is maintained by showing fast stabilized time for large number of nodes. Under uniform topology, since each node handles the similar number of packets, it removes uneven information on the random topology.

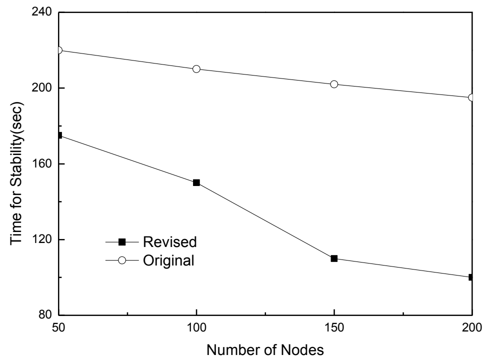

Figure 4.1: Time for stability on random topology

Another simulation result for the number of node which is changing parent and reliability is illustrated in Figure 4.3. For these simulations, we implement error model by adding the large noise over the wireless link. In Figure 4.3, we can see bigger difference when the number of nodes increases. While the original MintRoute just considers the number of lost packets, the revised algorithm employs the RSS to reflect real communication environments. The impact of RSS becomes larger and larger as the number of node increases. Moreover, counter based parent change prevents the more frequent parent change than original one in error condition. While the original MintRoute is very sensitive to small difference in LRi,j(t), the revised algorithm does not change the parent so high stability is brought.

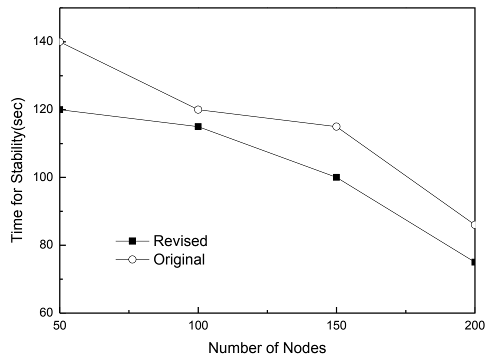

Figure 4.2 Time for stability on uniform topology

Figure 4.4 shows the reliability as a function of nodes with the same error model as the case done in Figure 4.3. From both Figure 4.1 and Figure 4.3, it is expected that revised algorithm is superior to original one because stability is likely to affect the reliability. In both cases, higher reliability is observed in large number of nodes because many nodes can contribute to accurate measurement on the link. On the other hand, some packets are drop due to collision between packets. However, advantage from large number of nodes overwhelms the disadvantage in MintRoute because lost packets are reflected to bad link quality. In addition to above facts, the difference between two schemes is brought by preventing backward parent selection. Even though there are a few parents, their effect will be larger and larger when a node locates in near the sink, that is, high level at the tree topology. Since all descendant nodes are affected by this node, Level Identifier in revised scheme enhances reliability so much. Correspondingly, Level Identifier and more reliable link computed by revised algorithm enhance the reliability by reducing the number of packets lost. The impact of these will become larger and larger when environment on wireless communications varies rapidly.

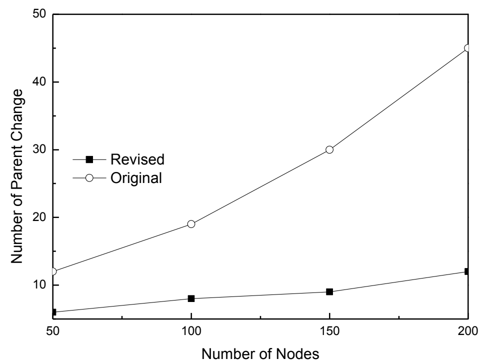

Figure 4.3: Number of node changing parent

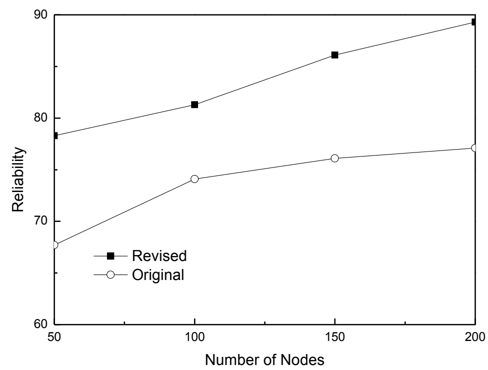

Figure 4.4: Reliability as a function of number of nodes

5 Conclusions and future work

Reliability in wireless sensor networks attracted many researchers' interest because there are many constraints on node itself such as low computing power and low-rate, short-range wireless radio communications as well as huge demands. These features often hamper high reliability in wireless sensor networks however reliability becomes essential in many applications. To meet this requirement, many research works have been proposed in each layer. Among those, MintRoute is one of well-known network layer protocol which guarantees reliability by choosing the reliable link to the sink on a tree topology.

Even though MintRoute seems to guarantee the acceptable performance for reliability in wireless sensor networks through periodical link quality measurement, several issues have not been explored yet. In this paper, we focused on stability of MintRoute. The main contribution for stability is conducted by introducing new selective link cost computation as well as parent selection scheme. A procedure for network initialized phase was also proposed in order to maintain stable networks in network initialized phase. Simulation results and their analysis demonstrated the impact of revised algorithm and validated the suitability of proposed scheme in the point of short stability time and enhance reliability.

Related to this work, more simulations on different topology, number of nodes, and other factors such as beacon interval will continue to evaluate performance. In addition, other parameters will be concerned for path selection procedure.

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