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スマートメータリングシステムにおける長寿命化のための負荷分散手法

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あらまし　スマートメータリングシステムにおいて, ノードの配置密度が高かったり, 通信距離が大きかったりする場合には, 隣接ノードが多くなる. このような状況で, シンクノードからのホップ数のみに基づいたルーティングを行なうと, 負荷の偏りが大きくなり, ネットワーク寿命の短縮や, 性能劣化の要因となる. 本稿では, トポロジーに基づいたルーティングと間欠周期の制御により上記の問題を解決する手法を提案する. シミュレーション評価の結果, 既存手法に対しネットワーク寿命を約 53%延長し, 平均遅延時間を約 21% 削減できることが明らかになった.

キーワード　スマートメータリングシステム, 無線センサーネットワーク, 負荷分散, 長寿命化, 間欠周期の制御

Load Balancing Techniques for Lifetime Prolonging in Smart Metering Systems

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Abstract　In smart metering systems, when the density of node is high or distance of communication range is large, the adjacent node number becomes large. If routing based on the number of hop from the sink node is used in such a network, the deviation of load will become large and it will shorten the network lifetime, also degrades other network performance. In this paper, we proposed the techniques solving the above-mentioned problem as routing technique and intermittent interval control technique. Simulation results show that proposal technique prolonged the network lifetime by about 53%, and reduced the average delay time by about 21%, comparing with existing method.

Key words　Smart Metering Systems, Wireless Sensor Networks, Load Balancing, Lifetime Prolonging, Intermittent Interval Control

1. Introduction

In recent years, the concern about the wireless ad-hoc network which nodes form a network autonomously has become strong. By using of wireless function, it is possible to collect and manage sensing information easily, without needing a special infrastructure, and attentions have gathered for the large type of applications in wireless ad-hoc networks. One of the application of wireless ad-hoc technology is a smart metering system. In smart metering system, each meter has a wireless communications function, therefore they can create a wireless ad-hoc network. Every meter is installed in each room of the apartment for used amount measurement of gas or electricity. Each meter transmits a data periodically to a central management node which we call the sink node. As a merit of this smart metering system, it is possible that realization of automatic meter inspection and the optimal supply plan etc.

The features of a smart metering system are that node density is high and packet generating frequency is low. However, it is required that the period of operation without battery exchange has to be several years. Therefore, saving energy in the operation of meters with limited battery life is an important problem for that still awaits resolution in the development of such smart metering systems. There are various approach about energy saving for wireless ad-hoc networks which like smart metering system. Most important researches are duty-cycled MAC [1-5] and energy-efficient routing protocols [6, 7]. The subject of this research is smart metering system where adjacent node number is large and packet generation frequency is low. If the communication range is long and the node density is large for a wireless multi-hop network, adjacent node number increases. It is confirmed that receiver-driven MAC protocol such as IRDT (Intermittent Receiver-driven Data Transmission) is suitable for the above-mentioned networks from a viewpoint of power consumption [8].

However, in such a wireless networks, there are the deviations of load and throughput between the nodes with the same number of hop to the sink. The number of forward nodes and the number of backward nodes differs in the nodes with the same number of hop due to the physical position shown in Figure 1. In this figure, there is a sink node in center, and we assume that other nodes deployed densely from hop 1 to hop 3. Then, we consider two of nodes which have same hop number 2. Node “A” is farther from sink, node “B” is closer to sink. We can see that node “A” has large area of backward nodes, and small area of forward nodes. On contrary, node “B” has small area of backward nodes, and large area of forward nodes. In spite of, this two node have same hop number to sink, but have different load and throughput.

Here, for a certain node, the adjacent node whose number of hop is smaller than itself is called forward node, and the adjacent node with the larger number of hop is called backward node. In the node group with the same number of hop to the sink, for the farthest node from the sink, the forward node number is small and the backward node number is large. This node will receive lot of packets from the backward nodes and it takes long time to transmit them, therefore the power consumption for relaying the data becomes very large. Many existing routing techniques only using the number of hop regardless of such a difference, then it results the variation in power consumption among nodes, and a factor of delay.

In this paper, we propose a load balancing technique, in order to solve the above-mentioned problem. In the sender node control, the difference of the load and throughput which are resulting from topology is reduced by using a detour route positively. A node has a small throughput and big load, it will send packets to the sideward nodes that has more throughput. In the receiver node control, data reception probability is controlled by changing the intermittent interval based on the load and throughput of the node. The performance of the proposal technique is evaluated by computation simulation. We use a network topology which is supposing an real apartment. We compared our proposed technique with existing IRDT system, and comparison metrics are network lifetime, average delay, and packet collection ratio. Here, we assume that the time until the first node run out battery is network lifetime.

This paper has the following composition. Section 2 explains the basic operation and the outline of an IRDT system. Section 3 explains the proposed load balancing technique. Section 4 describes evaluation results of the proposed technique. Finally, the conclusion and future work is stated in Section 5.

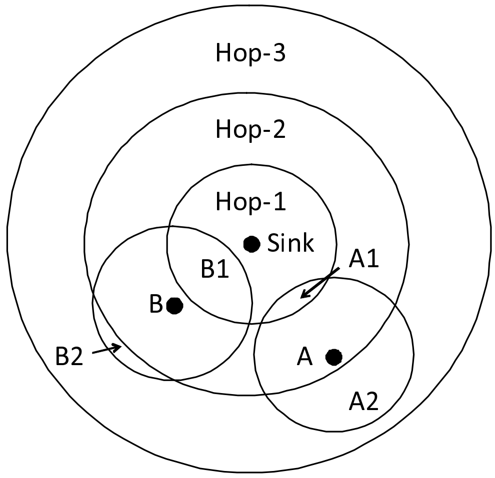


Figure 1 Forward and backward node numbers deviation problem due to topology. For node “A”, forward node area is “A1”, backward node area is “A2”. For node “B”, forward node area is “B1”, backward node area is “B2”.

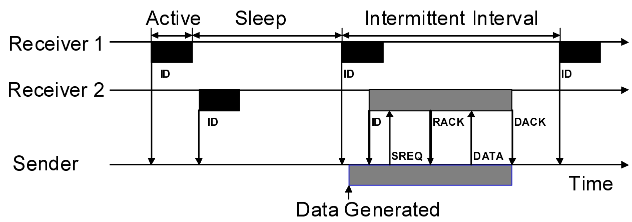


Figure 2 Data transmission process in the IRDT protocol

2. Overview of IRDT

2.1 MAC Protocol

In the IRDT protocol, each node intermittently sends its own ID over the network, and then assumes a “receive wait” state for a short time before entering the sleep state. In the receive wait state, the sender node waits for the ID of an appropriate receiver node, and if such an ID arrives, the sender responds with a send request (SREQ) packet. After receiving an acknowledgement (RACK) packet for the SREQ packet, the sender transmits a data packet and ends communication following receipt of an acknowledgement packet for the data (DACK). In Figure 2, the sender node checks the ID of Receiver 2 and accepts it as an appropriate receiver. The appropriateness of a receiver is determined on the basis of the routing protocol.

2.2 Routing Protocol

The routing algorithm of IRDT is based on multi-hop routing,

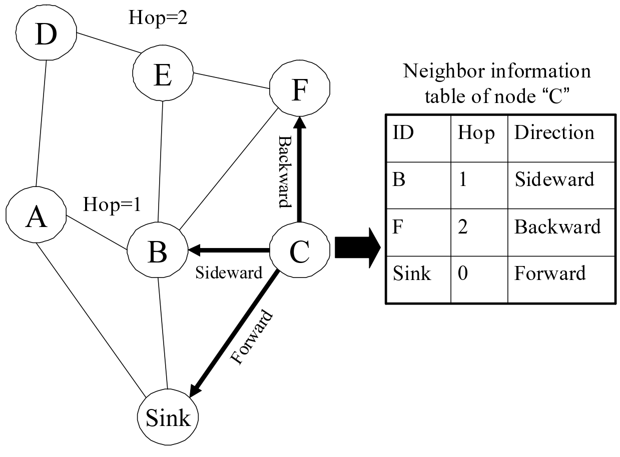


Figure 3 Neighbor information table

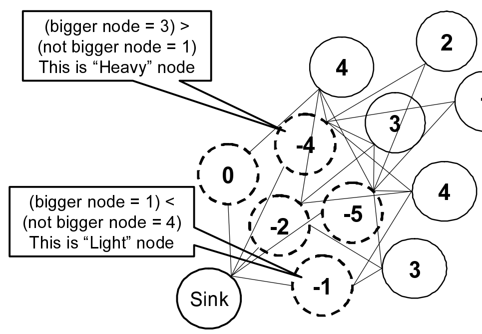


Figure 4 Example of L and H node. Inside value is initial RA. Dotted line nodes belong to hop 1 area

where each node is involved in the process of relaying the packet. Although minimum-hop routing is preferable for achieving lower energy consumption for a packet, in some situations certain nodes cannot be used for minimum-hop routing, owing to poor conditions for radio wave transmission or node failure. Therefore, for higher flexibility, the routing algorithm of IRDT considers alternative paths in addition to the minimum-hop route. All nodes contain a configuration table for managing neighbor node information. Nodes update their own tables by periodically exchanging “ID” packets. If the minimum number of hops from a node to the sink node is denoted as h, the number of hops for any of its neighbor nodes is $h-1$, h, or $h+1$, and we refer to these neighbors as forward nodes, sideward nodes, and backward nodes, respectively. Some example is shown in Figure 3. When a sender receives the ID of a forward node, it returns an SREQ packet. We define communication failure as a situation where the sender cannot obtain RACK and DACK packets from the receiver. Sideward nodes are selected when communication failure has occurred with all forward nodes. All data packets contain a time-to-live (TTL) field in order to avoid heavy repetition of data relay. For each relay of a data packet, TTL is decremented by one, and when TTL becomes 0, the data packet is discarded. There is a possibility that two or more forward nodes exist. If there are many the forward nodes, ID waiting time becomes short and power consumption for data transmission is also small.

3. Load Balancing Technique

3.1 Sender Node Control

Here, we describe the sender node control. As an index showing the operation situation of a node, the number of forward nodes and the number of backward nodes can be considered. The node with many backward nodes and few forward nodes will receive many packets, and also it takes long time for transmitting a packet, therefore this node's power consumption becomes very large. It is required to improve the throughput for such a heavy load node. Our technique increases the number of possible receiver nodes for a node with large load, and performs load balancing. The routing method of IRDT determines probability of data transmitting, when received a ID from data receiver node. This existing routing is only based on the hop number information. We propose a technique of determining the transmission probability at sender node. But, our technique is not only based on the hop number but also using a topology characteristic information.

Each node holds the value which is showing the load of this node, calling it “Relaying Ability”, and also holds the number of hop to the sink. We omit “Relaying Ability” as RA. There is a mechanism that each node broadcasts self ID periodically in the existing IRDT system, and if the self RA is transmitted together with the ID, it can share easily between adjacent nodes. The proposal technique is determining data transmission probability to certain node by using the hop number and the RA. Each node determines it's RA value by the following two steps.

Step 1: Calculation of Initial “Relaying Ability” and Determination of “Heavy Node” or “Light Node”

At first, each node calculates the initial RA. It is the difference of the number of forward nodes and the number of backward nodes, and it expresses by the following formula.

$$RelayingAbility \leftarrow (N_f - N_b) \tag{1}$$

In next, the initial RA is mutually exchanged by each pair of the sideward nodes. A node compares the number of nodes whose RA is higher than it with the number of nodes whose RA is lower than it. If the former number is bigger, the node is called a “Light” node or L node,if not the node is called a “Heavy” node or H node. This “Heavy” or “Light” label expresses node's relative operation conditions. A example is shown in Figure 4.

Step 2: Updating RA value of L nodes

At this step, each node updates its RA value. Since H nodes can not afford a additional data relay, set 0 to the RA. Every L nodes update the RA value by Eq (2), and notifies that value to the all sideward nodes. Then, H nodes transmit data to L nodes positively, since it can average the power consumption of certain hop area nodes. When a H node transmits data to a L sideward node, it will use the L node's RA value as probability of data transmission.

$$RelayingAbility \leftarrow \min\left\{\frac{N_f}{N_{Side-H}} \cdot \alpha, 1\right\} \tag{2}$$

Here, N_f is the forward node number, we think that it should be

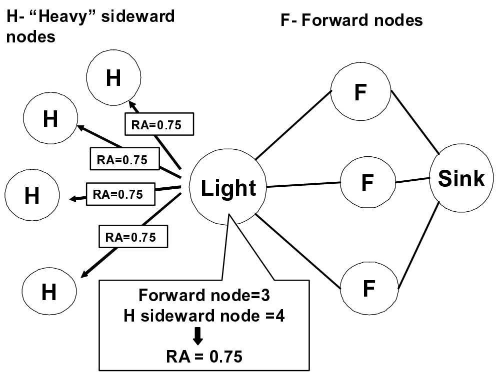


Figure 5　L nodes inform RA to all H sideward nodes

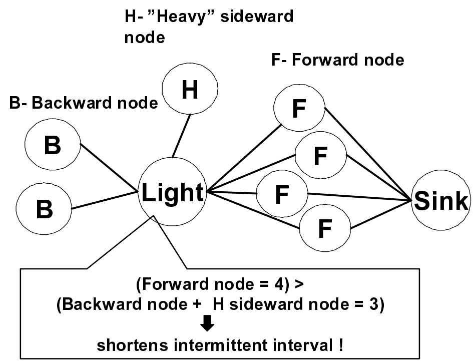


Figure 6　L node shortens the intermittent interval

proportional to the RA. N_{Side-H} is the number of H sideward nodes, this value is inverse proportion to the RA. α is a constant value. This parameter controls traffic from H nodes to L nodes. If network density is high, it is required load balancing more, therefore α should be big value.

Data sending node's operation

- When it receives ID from a forward node, it sends data.
- When it receives ID from a sideward node:
  - If itself is L node, it do not send data.
  - If itself is H node, sending probability is RA_{ID}.

RA_{ID} is ID sender node's RA. The L node which have small traffic transmits only to forward nodes. The H node which have big traffic transmits forward nodes and L sideward nodes for load balancing.

3.2 Receiver Node Control

Here, we describe the receiver node control. The controlling of intermittent interval is also considered as a load balancing technique. For such a node which has many backward (large load) and few forward nodes (weak throughput), it is desirable to set up longer intermittent interval to reduce the number of data receiving. On the other hand, the node whose the number of forward nodes is large enough, and has few backward nodes, it should set up shorter intermittent interval to increase the number of data receiving. Thus, it is possible to equalize the number of times of receiving data by controlling intermittent interval in consideration of throughput and load.

Step 3: Changing intermittent interval at H and L nodes

Here, we propose a technique of determining an intermittent interval using the RA value calculated at Step 2 for load balancing. We define that T_0 is initial intermittent interval, T_t is intermittent interval at clock t.

- L Node

A L node raise data relaying frequency more, when the forward node number (N_f) is still bigger than sum of backward (N_b) and H sideward node number (N_{Side-H}). This situation is shown by Figure 6. Therefore, it sets up the intermittent interval which is shortened by Eq (3). However, the intermittent interval should be changed with minimum limitation. Because, this limitation make node not to raise data relaying load too much.

$$T_{t+1} \leftarrow \max\left\{T_t \cdot \frac{N_b + N_{Side-H}}{N_f}, T_0 \cdot 0.5\right\} \tag{3}$$

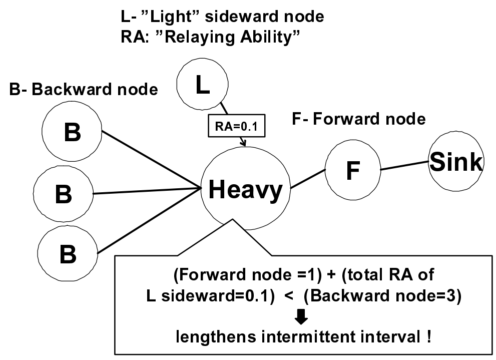


Figure 7　H node lengthens the intermittent interval

- H Node

According to the Eq (4), a H node sets up longer intermittent interval to lower data relaying frequency, when it does not have sufficient RA from "Light" sideward nodes and forward node. It means that backward node number is bigger than the addition of number and total RA of "Light" sideward nodes (N_{given}). This situation is shown by Figure 7. However, there is maximum limitation on the changing of intermittent interval. This condition prevents node's relaying frequency becomes too slowly.

$$T_{t+1} \leftarrow \min\left\{T_t \cdot \frac{N_b}{N_f + N_{given}}, T_0 \cdot 2\right\} \tag{4}$$

4. Performance Evaluation

4.1 Simulation Scenario

We assume a simulation network with the topology shown in Figure 8. The main parameters of this setup are shown in Table 1. Here, the sink node is in the bottom center, and the remaining 119 nodes transmit packets to the sink node randomly in accordance with a predefined rate. Our target application is gas metering system, therefore we used this grid-like topology which is based on real apartment. The assumed apartment has 17 floor and there are seven rooms on each floor, there is a gas in each room. We suppose that the vertical distance of meters is 3 m and horizontal distance of meters is 4 m, and meter's transmission range is 10 m.

4.2 Numerical Results

4.2.1 Power consumption and network lifetime

Here, the comparison result about the power consumption of the

Table 1 Simulation Parameters

Parameter	Value
Packet generation rate	0.001 packets/s
Initial battery	2 mAh
Initial intermittent interval	1 s
Current during transmission	20 mA
Current in the waiting state	25 mA
Current during reception	25 mA
Current in the sleep state	0 mA
Transmission rate	100 kbps
Packet size	128 bytes

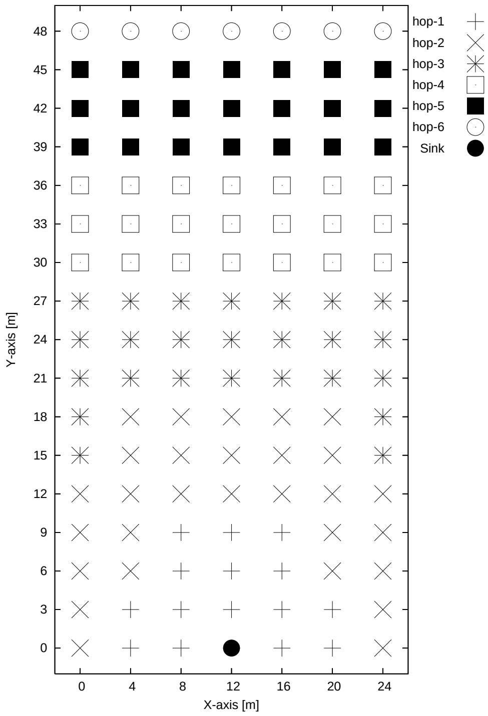


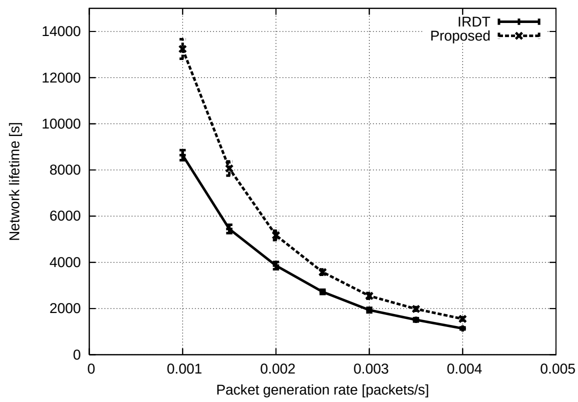
Figure 8 Simulation Topology: Nodes in same points have same hop number to sink

proposal technique and IRDT is described. Figure 9(b) shows average power consumption of each hop area. The amount of consumed power on a H node is very high in the existing IRDT system in compared with proposal technique, because of the IRDT's routing is only depending on the number of hop. Also when the number of hop is the same, that average consumption power differs greatly at L or H nodes. The case of the proposal technique, since a H node transmits much traffic to the sideward L nodes to reduce ID waiting time and the intermittent interval is also controlled, it is confirmed that power consumption of these nodes is balanced.

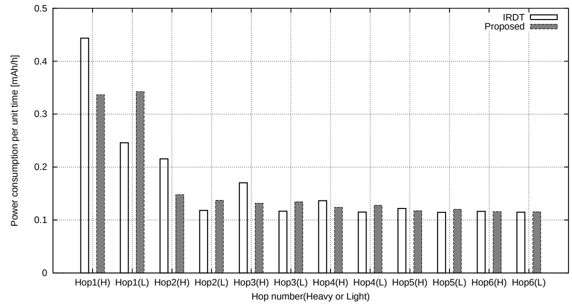
Since the power consumption is equalized by the proposal technique, Figure 9(a) shows the result that the network lifetime was prolonged. When the packet generation ratio is raised, this figure shows how the network lifetime is changing. With increase of network load, the network lifetime has fallen, but the proposal technique has longer network lifetime than IRDT.

4. 2. 2 Average delay time

The comparison result of the average delay time in the proposal technique and IRDT system is described. Figure 10(a) shows change of the average delay time when a packet generation ratio



(a) Network lifetime



(b) Average power consumption at each hop

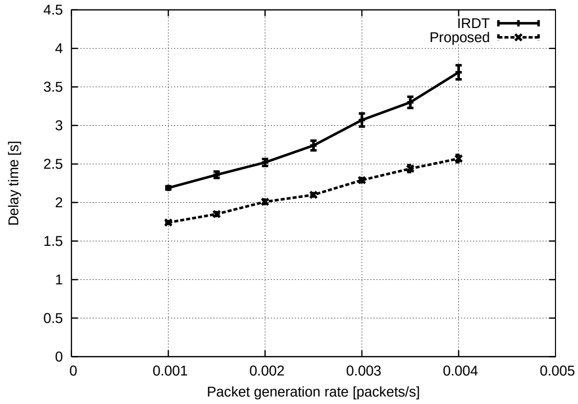
Figure 9 Comparison of power consumption performance

changed. From the result, we can see that average delay time in the proposal technique is smaller than IRDT. Furthermore, even if network load increases, only a few amount is increasing average delay time for proposal technique. But delay of the IRDT system is increasing more quickly, since ID reception waiting event occurs at lot of node and it will require time for data transmission, when network load increased. Sideward nodes is positively used in the proposal technique, even if traffic increases, the proposal technique has load tolerance more than IRDT.

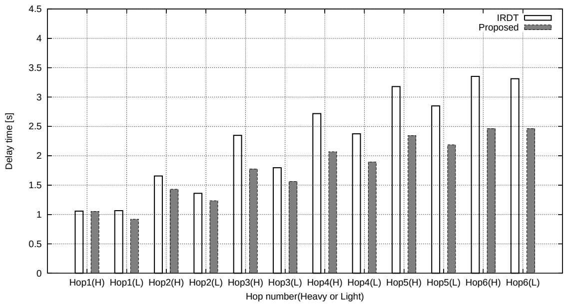
The comparison result of the average delay time to the sink arrival from each hop is shown in Figure 10(b). In the hop 1, the sink is directly connected and there is no difference in delay time much. After the hop 2, it can confirm that delay time is smaller in proposal technique. In a H node, since it can transmit to the sideward nodes at an early stage by the proposal technique, then ID waiting time reduced. In a L node, however the traffic from the sideward nodes increases with the proposal technique, data can be transmitted quickly, since the operating ratio of the forward nodes became high by shortening of intermittent interval.

4. 2. 3 Packet collection ratio

The comparison result of the packet collection ratio in the proposal technique and IRDT system is described here. When the packet generation ratio per node is raised, it is shown in Figure 11(a) how a packet collection ratio changes. It seems that the packet collection ratio is falling when network load increased. Since packet collision and hidden terminal problem probability will increase if traffic increases, therefore the packet collection ratio falls. The comparison result of the average packet arrival ratio in each hop is shown in Figure 11(b). It is confirmed that the proposal technique

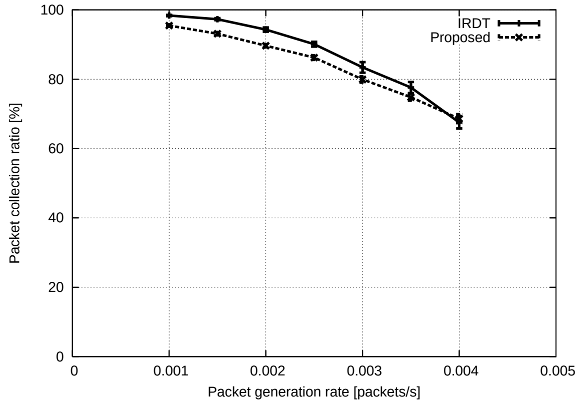


(a) Average delay time

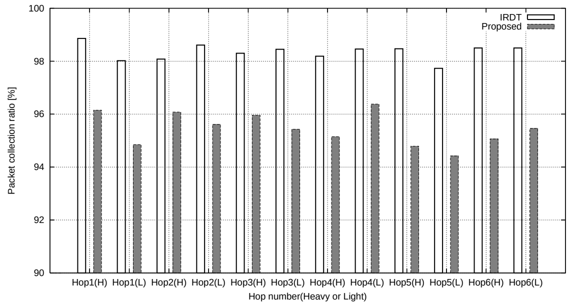


(b) Average delay time at each hop

Figure 10 Comparison of average delay time performance



(a) Packet collection ratio



(b) Packet collection ratio at each hop

Figure 11 Comparison of packet collection ratio performance

and IRDT system can maintain a certain packet arrival ratio at each hop and each node.

However, in the proposal technique, The packet collection rate is falling a little. The reason is that the probability of the packet collision going up with the proposal technique since the increasing of traffic at the L node. IRDT has a contention-based MAC protocol. Therefore, packet collision and hidden terminal problems occur with a certain probability. But, when network load is enough low, packet drop ratio is very low. As solution method for this problem, the addition of a back-off function can be considered.

5. Conclusion

In this paper, we proposed load balancing techniques for the smart metering systems, when the topology is dense and communication range is large. The proposed load balancing techniques consists of sender node control and receiver node control. Sender node control makes nodes transmit positively to the sideward nodes. Receiver node control adjusts data relay load for nodes by changing the intermittent interval. Our evaluation results show that it is possible to prolong the network lifetime by about 53%. And also our proposal technique can decrease the average delay time by about 21%, comparing with existing IRDT. In the future, we are considering evaluation about more different topology and simulation scenario, and the robustness that assumed to be addition and failure of nodes.

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