Master's Thesis

Title

Load Balancing Techniques for Lifetime Prolonging in Smart Metering System

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Abstract

In recent years, the smart metering systems which can monitor the amount of the gas or the electric power at each home in real time are being developed broadly. In these systems, each meter has a communication function and forms a wireless network with each other. Since these meters are usually driven by the small battery by which capacity is restricted, it is important to control the power consumption and to prolong the operating time of such a smart metering system.

In cases where such a smart meter ring system is installed in a large-scale apartment house, the allocation density of meter becomes high and a wireless multi-hop network with very many adjacent nodes will be constructed. In the wireless multi-hop network where installation density is high, since many detours are obtainable, in the case of a method which performs intermittent operation, it is expectable to control power consumption by reduction of waiting time. On the other hand, application of the simple routing protocol only based on the number of hop from a sink node will generate the problem that the difference of the power consumption between the nodes with the same number of hop to the sink node will become large.

For example, at a node located in the location close to the sink node, since there are more adjacent nodes of a transmission destination than the adjacent nodes of a reception destination, the communication frequency of those nodes is low and their operating time is short and there is little power consumption. However, although the number of hop to the sink is the same, in a node located in the distance from a sink node, power consumption will become large. Due to such a unbalanced load problem from topology, the network lifetime not only becomes short, but also delay time and packet loss rate get worse.

In this paper, we propose a load balancing techniques to solve the above-mentioned problem. The proposal technique consists of sender node control and receiver node control. Sender node control makes nodes to transmit positively to the sideward node which has same number of hop to the sink. Receiver node control adjusts data relay load for nodes by changing the intermittent interval which is sleep and awake time interval. Our evaluation results show that proposal technique is possible to prolong the network lifetime, while maintaining other network performance such that packet collection ratio and packet delivery delay time.

Keywords

Smart Metering Systems
Wireless Sensor Networks
Lifetime Prolonging
Load balancing
Duty cycle control

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1 Introduction

In recent years, the concern about the wireless ad-hoc network which nodes form a network autonomously has become strong. By use of wireless, 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 which has applied wireless ad-hoc technology is a smart metering system. In smart metering system, each meter has a wireless communications function, and a meter is installed in each room of the apartment, therefore those meters can create a wireless ad-hoc network. Each meter transmits a data periodically to central management node which we call a 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 feature of a smart metering system is 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 sensor nodes with limited battery life is an important problem for that still awaits resolution in the development of such a wireless ad-hoc networks. Various approaches to saving energy have been developed, for example, the application of MAC protocols with sleep control and multi-hop routing [1-3].

The subjects of this research are the wireless networks where adjacent node number is large and packet generation frequency is low. For example, for a gas metering system, topology is dense and has low packet generating frequency. 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 [4]. 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. 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.

The example of the network, where node density is high and communication distance is long, is shown in Figure 1. The whole network is divided into three hop. We pay attention to the node “A” and the node “B” which are belong to the hop 2. Since it is close to a sink, the node “B” has many forward nodes and few backward nodes. On the contrary, since it is far from a sink, the node “A” has few forward nodes and many backward nodes. Thus, it arises the deviation problem of the load and throughput resulting from topology. In the node group with the same number of hop to the sink, for a node with farer to the sink, the forward node number gets small and the backward nodes number gets big. Therefore it takes time for the number of data to receive to increase and transmit for such a node, 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

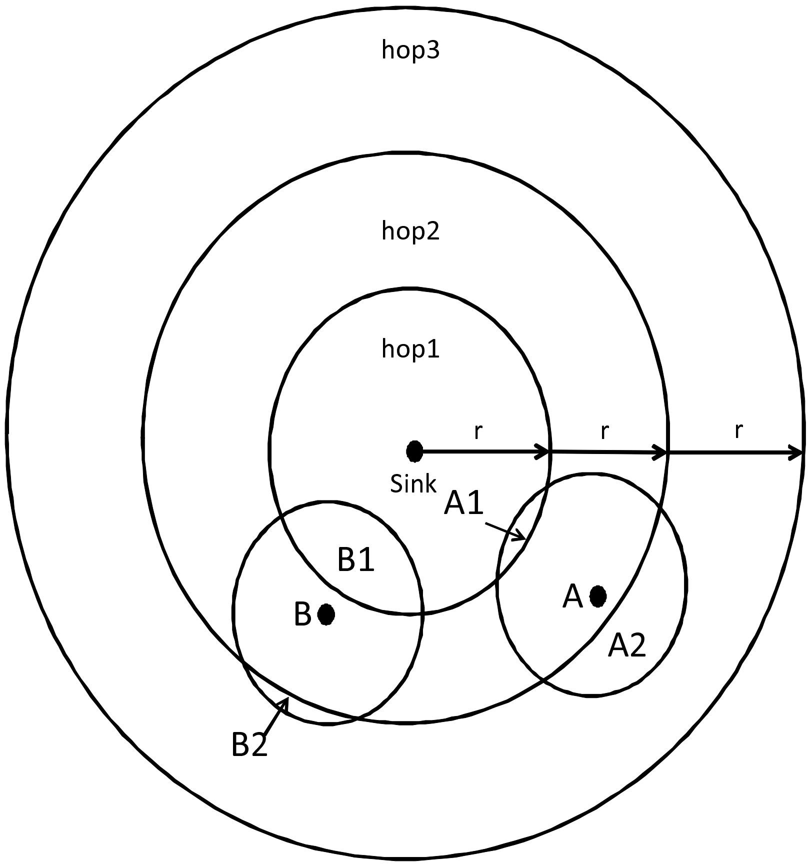


Figure 1: Forward and backward node numbers deviation problem due to topology. For node “A”, forward node area is “A1”, backward node area is “A2”. For node “B”, forward node area is “B1”, backward node area is “B2”.

results the variation in power consumption among nodes, and a factor of packet loss.

In this research, in order to solve the above-mentioned problem, a load balancing technique are proposed. The proposal technique consists of controls which a data sender node performs, and a data receiver node performs. In the sender node control, the difference of the load and throughput which are resulting from topology is reduced by using a detour course 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. By the above mentioned techniques, we aim at the load balancing of the whole network and prolonging of the network lifetime and improvement in a packet delay time.

The performance of the proposal technique is evaluated by computation simulation. Moreover, we use the 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, the time until the first node run out battery is determined network lifetime.

This thesis has the following composition. Section 2 describes about related works. Section 3 explains the basic operation and the outline of an IRDT system. Section 4 explains the proposed load balancing technique. Section 5 describes evaluation results of the proposed technique. Finally, the conclusion and future work is stated in Section 6.

2 Related Work

There are a lot research about energy saving for wireless ad-hoc networks which like smart metering system. They are classified into research about duty-cycled MAC and research about load balancing and lifetime prolonging routing protocols. In this section, we introduce simply each of them.

2.1 Duty-Cycled MAC Protocols

Since sleeping nodes consume considerably less energy than idling nodes, sensor nodes enter the sleep state when they are not sending or receiving data in order to reduce energy consumption. However, in such cases, nodes must be able to control the time intervals at which they wake up in order to communicate with one another. Control methods for intermittent operation are classified into two types: synchronous [5-9] and asynchronous [10-16]. Asynchronous MAC protocols can be divided into two subcategories: sender-driven MAC protocols (such as LPL [12], B-MAC [11], WiseMAC [13], and X-MAC [10]) and receiver-driven MAC protocols (such as RI-MAC [14] and IRDT [15]).

2.1.1 Synchronous MAC protocols

In synchronous MAC implementations, such as S-MAC [5] and T-MAC [6], scheduling information which specifies the cycles of the active and sleep periods is shared via synchronization packets. These packets align the active and sleep intervals of neighbor nodes, which wake up only during the common active time intervals to exchange packets. Since the active intervals are usually short, substantial amounts of energy can be saved. However, energy is still wasted since the strict synchronization of the clocks of neighbor nodes imposes high overhead.

In S-MAC [5], at the beginning of the active period, nodes exchange SYNC information with their neighbors to ensure that the node and its neighbors wake up concurrently. This schedule is only adhered to locally, resulting in a virtual cluster, which mitigates the need for synchronization of all nodes in the network. Nodes that lie on the border between two clusters maintain the schedules of both clusters, thus maintaining connectivity across the network. After the synchronization information is exchanged, the nodes send data packets by using request-to-send (RTS)/clear-to-send (CTS) signals until the end of the active period, after which they enter the sleep state. S-MAC saves energy with the use of periodic sleep intervals and reduces the amount of energy wasted as a result of idle listening. Although S-MAC improves the energy efficiency, it causes delays in multi-hop data delivery and wastes energy due to fixed duty cycling.

In T-MAC [6], which is an improvement on S-MAC, nodes enter sleep state when no activation event has occurred for a certain amount of time, which enhances the energy efficiency. In contrast to S-MAC, it operates with fixed-length slots and uses a time-out mechanism to dynamically determine the end of the active period. The time-out value (TA) is set to span a small contention period and the time necessary for an RTS/CTS exchange. If a node does not detect any activity within the time-out interval, it assumes that no neighbor is ready to communicate with it, and enters the sleep state. T-MAC adapts to traffic fluctuations in the network and improves the energy efficiency more drastically than S-MAC. However, a certain amount of energy is still wasted due to the fixed duty cycle in the fixed time-out mechanism.

2.1.2 Asynchronous MAC protocols

In asynchronous MAC protocols, on the other hand, nodes do not exchange synchronization information for transmission or reception of data, thus enabling nodes to operate with their own independent duty cycles. Therefore, such protocols are not burdened by the overhead associated with the synchronization process. Asynchronous MAC protocols can be divided into two subcategories: sender-driven MAC protocols (such as B-MAC [11], WiseMAC [13], and X-MAC [10]) and receiver-driven MAC protocols (such as RI-MAC [14] and IRDT [15]). First, we introduce some classic sender-driven protocols.

B-MAC [11] utilizes a long preamble to achieve low power consumption during communication. If a node is ready to send data, first it sends a preamble which is slightly longer than the sleep period of the receiver. During the active period, the receiver node samples the channel, and if a preamble is detected, it remains awake to receive the data. With the inclusion of a long preamble, the sender ensures that at some point during the preamble the receiver will wake up, detect the preamble, and remain awake in order to receive the data. While B-MAC performs rather well, it suffers from an overhearing problem, in that receivers that are not the target of the sender also wake up during the long preamble and remain awake until the end of the preamble in order to find out if the packet is destined for them. This process wastes energy for all non-target receivers within the transmission range of the sender, and thus the long preamble dominates the energy consumption and increases the per-hop latency.

The method in WiseMAC [13] is similar to that in B-MAC, with the difference that the sender learns the wake-up periods of the receivers and schedules its transmissions in a manner that reduces the length of the extended preamble. The size of the preamble is initially set to be equal to the sampling period. However, the receiver might not be ready at the end of the preamble; as a consequence, factors such as interference may result in energy waste due to over-emitting. Moreover, over-emitting increases proportionally to the length of the preamble and the data packet since there is no handshake between the sender and the target receiver.

In contrast to B-MAC, X-MAC [10] utilizes short preambles with target address information instead of a long preamble, which solves the overhearing problem in B-MAC. When a receiver wakes up and detects a short preamble, it checks the target address included in the preamble. If the node is the intended receiver, it remains awake for the incoming data; otherwise, it immediately reenters the sleep state. This mechanism can decrease the per-hop latency and the amount of energy wasted on waiting for data transmission. This approach is simple to implement and achieves low power consumption for communication, but becomes less energy efficient and fails to guarantee a worst-case delay as the traffic load increases.

A different approach is adopted in RI-MAC [14] and IRDT [15], which are receiver-driven MAC protocols. Contrary to sender-driven protocols, where the sender initiates the data transmission, RI-MAC offers receiver-initiated listening and low power consumption. The goal of RI-MAC is to reduce the channel occupancy time, which is achieved by ensuring that the sender remains active and waits silently until the receiver sends a short packet to explicitly signal that it is ready for data transmission. Since only such short packets and the transmitted data occupy the medium in RI-MAC, there are no preamble transmissions as in B-MAC and X-MAC, and the occupancy of the medium is drastically decreased, allowing other nodes to exchange data during that time.

2.2 Energy Aware Routing Protocols

Here, we introduce some energy aware routing protocols, clustering based hierarchical routing [17-21] and link cost considered lifetime maximizing routing protocols [22-24]. This is some useful surveys on routing protocols in wireless sensor networks [3, 25].

2.2.1 Hierarchical routing

LEACH[17] is a dynamic energy efficient cluster head protocol proposed for WSN using homogeneous stationary nodes . In LEACH all nodes have a chance CH and therefore energy spent is balanced for every node. The CH for the Clusters are selected based on their energy load. After its election, the CH broadcasts a message to other nodes, which decide which cluster they want to belong to, based on the signal strength of the CH. The clusters are formed dynamically in each round and the data collection is centralized. A TDMA schedule created by the CH is used to gather data from the sensors.

PEGASIS[18] is an extension of the LEACH protocol, and simulation results show that PEGASIS is able to increase the lifetime of the network twice as much as the LEACH protocol. PEGASIS forms chains from sensor nodes, each node transmits the data to neighbor or receives data from a neighbor and only one node is selected from that chain to transmit data to the BS. The data is finally aggregated and sent to the BS. PEGASIS avoids cluster formation, and assumes that all the nodes have knowledge about the network , particularly their positions using a greedy algorithm. Although clustering overhead is avoided, PEGASIS requires dynamic topology adjustment since the energy status of its neighbor is necessary to know where to route its data. This involves significant overhead particularly in highly utilized networks.

HEED[19] is an extension of LEACH and uses residual energy and node degree or density asymmetric for cluster selection to achieve power balancing. HEED has the following features. Prolongs network lifetime by distributing energy consumption, terminates clustering process within a constant number of iterations, minimizes control overhead and produces well distributed

CHs and compact clusters. HEED selects CHs based on the residual energy of the SNs and intra-cluster communication cost as a function of cluster density or node degree. HEED clustering improves network lifetime over LEACH clustering randomly selects CHs and cluster size and therefore nodes die faster.

2.2.2 Network lifetime aware routings

Maximum lifetime energy routing[22] presents a solution to the problem of routing in sensor networks based on a network flow approach. The main objective of the approach is to maximize the network lifetime by carefully defining link cost as a function of node remaining energy and the required transmission energy using that link. Finding traffic distribution is a possible solution to the routing problem in sensor networks and based on that, comes the name "maximum lifetime energy routing". The solution to this problem maximizes the feasible time the network lasts. In order to find out the best link metric for the stated maximization problem, two maximum residual energy path algorithms are presented and simulated

Maximum lifetime data gathering[23] models the data routes setup in sensor networks as the maximum lifetime data gathering problem and presents a polynomial time algorithm. The lifetime T of the system is defined as the number of rounds or periodic data readings from sensors until the first sensor dies. The data-gathering schedule specifies for each round how to get and route data to the sink. A schedule has one tree for each round, which is directed from the sink and spans all the nodes in the system. The system lifetime depends on the duration for which the schedule remains valid. The aim is to maximize the lifetime of the schedule. An algorithm called maximum lifetime data aggregation (MLDA) is proposed. The algorithm considers data aggregation while setting up maximum lifetime routes.

Minimum cost forwarding[24] aims at finding the minimum cost path in a large sensor network, which will also be simple and scalable. The protocol is not really flow-based, however since data flows over the minimum cost path and the resources on the nodes are updated after each flow, we have included it in this section. The cost function for the protocol captures the effect of delay, throughput and energy consumption from any node to the sink.

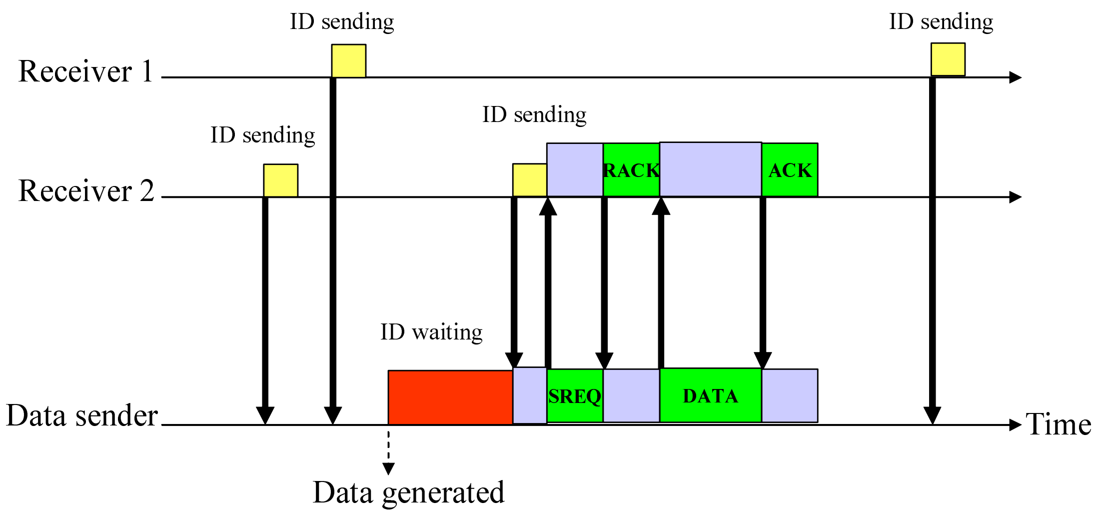


Figure 2: Data transmission process in the IRDT protocol

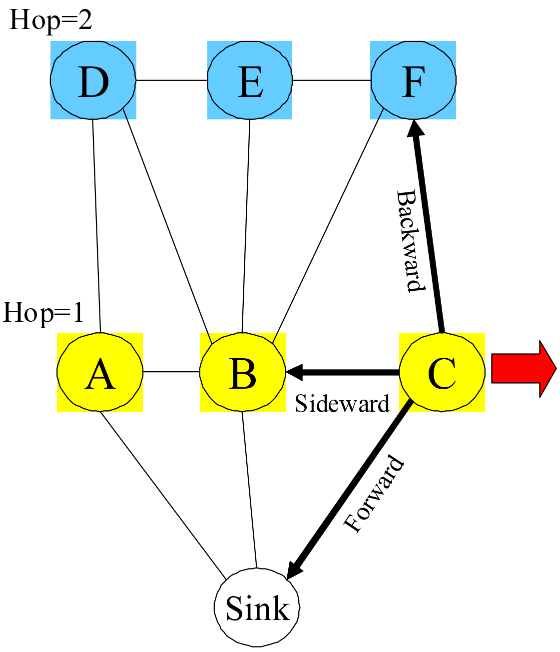
3 Overview of IRDT

3.1 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). Such intermittent operation involving Receiver 1 and Receiver 2 is shown in Figure 2. Here, 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 (Section 3.2). The sender node can choose from one or more communication candidates, thus improving the communication reliability and reducing the time spent by the sender waiting for receivers to wake up.

3.2 Routing Protocol

The routing algorithm of IRDT is based on multi-hop routing, where each node is involved in the process of relaying the packet. Although minimum-hop routing is preferable for achieving lower energy consumption, 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



Neighbor information table of node "C"

ID	Hop	Direction
B	1	Sideward
F	2	Backward
Sink	0	Forward

Figure 3: Management of neighbor information table

minimum-hop route. All nodes contain a configuration table for managing topology information. Nodes update their own tables by periodically exchanging topology information packets, and they use their own tables to determine the number of hops to the sink node. 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. For example, regarding node "C" in Figure 3, "Sink" is a forward node, "B" is a sideward node, and "F" is backward nodes. For minimum-hop routing, the sender node should select forward nodes as receivers. 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, and backward nodes are selected if communication fails with all sideward 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. A node will not select a sideward node or a backward node if doing so would result in data packet loss due to the TTL mechanism.

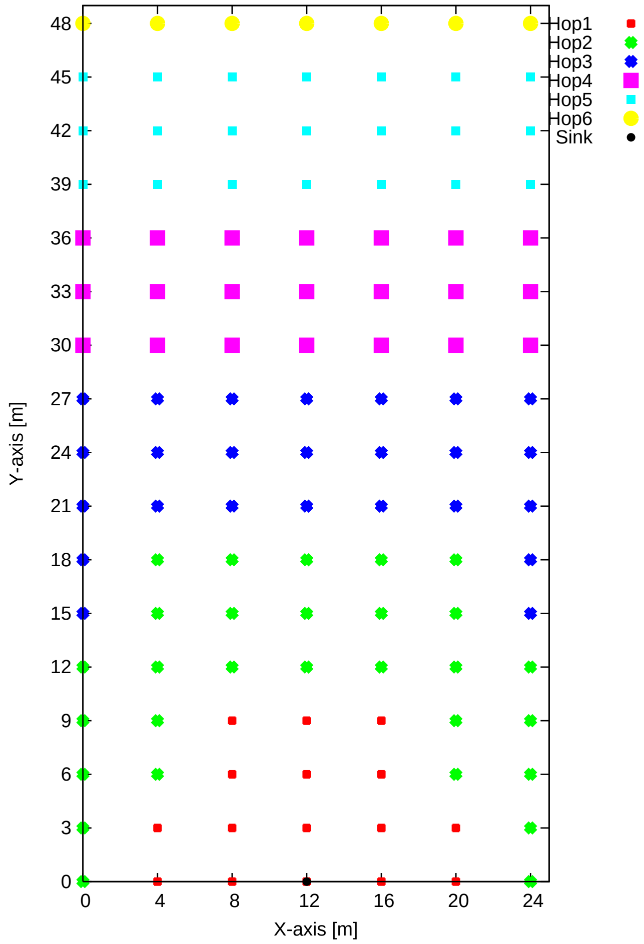


Figure 4: Topology:nodes in same color have same hop number

3.3 The Problem with IRDT

The subject of this thesis is the wireless networks where the communication range is long and node density is high, or the wireless multi-hop networks where adjacent node number is big. In such a wireless networks, there is a deviation problem 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 also differs in the node with the same number of hop due to the physical position.

Existing routing technique only using the number of hop regardless of such a difference, then it results the variation in power consumption among nodes and limited network lifetime. When existing IRDT protocol is applied to topology which shown in Figure 4, Figure 5 shows average power consumption of all nodes in hop 1. The numbers of farer node from the sink are 4,6,9, and those nodes power consumption very large compared other nodes.

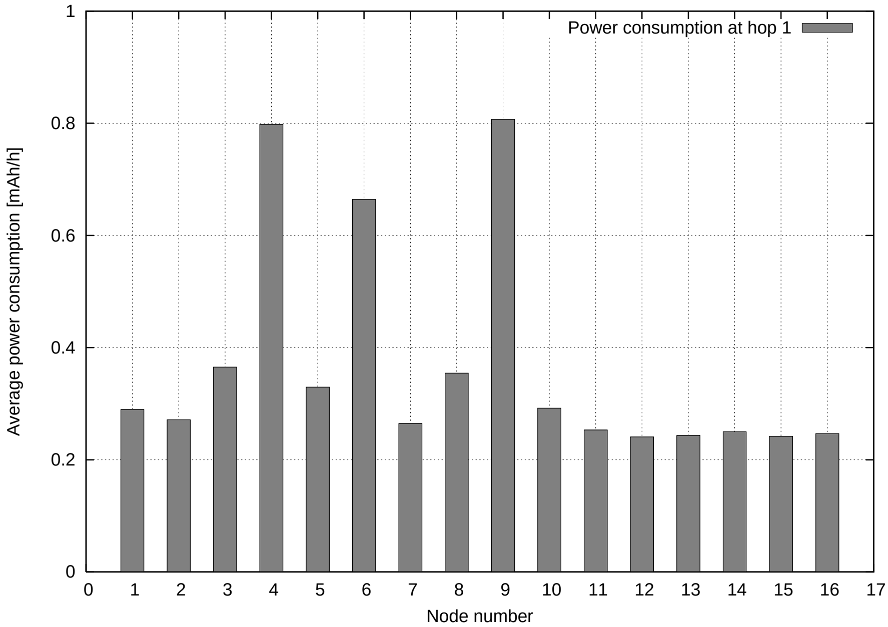


Figure 5: Power consumption at hop 1 nodes

4 Load Balancing Technique Based on Routing Method

In this section, we propose a load balancing technique. The proposal load balancing technique consists of sender node control and receiver node control. With the control of sender node, load balancing is performed in a node with few forward nodes and many backward nodes by making it transmit positively to the sideward nodes which has same number of hop to the sink. With the control of receiver node, data reception frequency is changed by controlling the intermittent interval based on the load of node.

4.1 Sender Node Control

Here, we describes 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. If there are many forward nodes, ID is intermittently received from those nodes so that, waiting for ID time becomes short which required to transmit a packet.

If there are many backward nodes, SREQ will be received from those nodes so that , data reception probability becomes large. The node with many backward nodes and few forward nodes will has many packets to receive, and also it takes long time for transmitting a packet compared with the other nodes of the same number of hop, therefore this node's power consumption becomes very large. In Figure 6, node "B" has six backward nodes and one forward node. Node "B" will receive lot of packets from this six backward nodes, and it will take long time to send this packets to

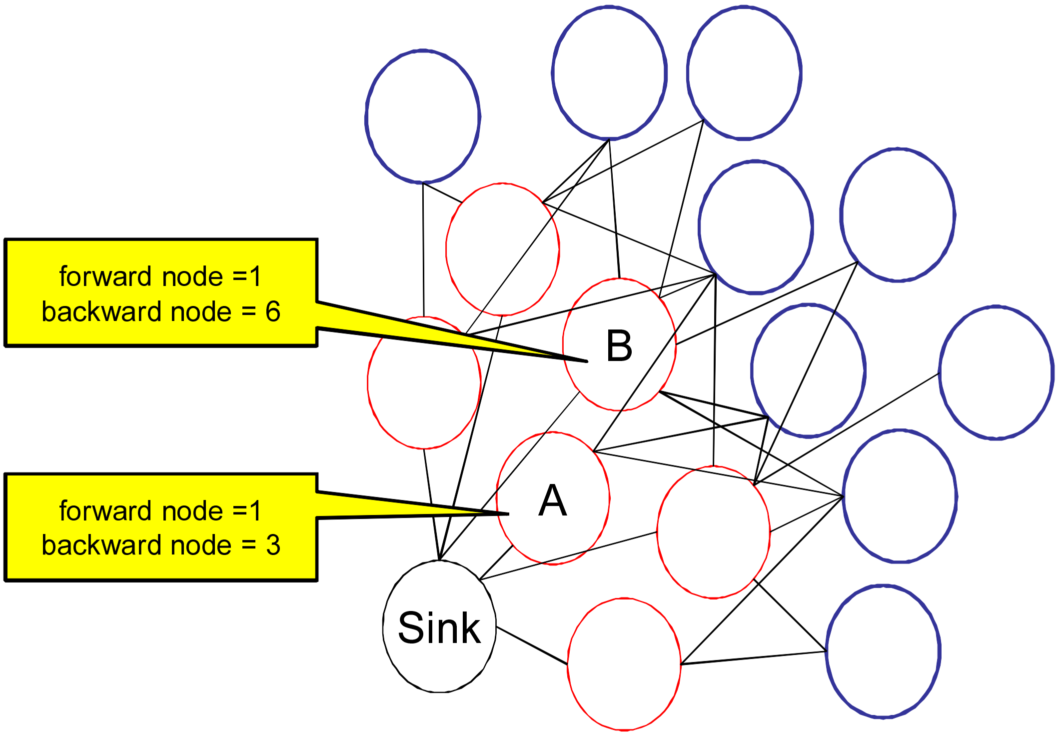


Figure 6: Packet relaying load difference at nodes. Red nodes are in hop 1, Blue nodes are in hop 2.

one forward nodes. Therefore, node “B” will consume lot of power for packet relaying. For node “A”, it has only three backward nodes and one forward node, then it will receive approximately 2 times fewer packets than node “B”. In spite of this two nodes have a same hop number to the sink, they have a big difference at power consumption ratio.

It is required to improve the throughput for such a heavy load node. To do this, it is possible that the node with large load makes the number of transmission nodes increase, and performs load balancing. The routing technique which the IRDT system has applied is the technique of determining probability of whether a sending node transmits data, when received a ID from data receiver node.

This technique is called the existing routing technique. When the existing routing technique determines probability of whether transmit data or not to a certain node, it uses the hop number information which is to the sink node. Then, we propose a technique of determining the transmission probability at sending node like the existing routing technique. 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 operation situation of this node, calling it "Relaying Ability", and also holds the number of hop to the sink. There is a mechanism that each node broadcasts self ID periodically in the existing IRDT system, and if the self "Relaying Ability" 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 "Relaying Ability". Each node determines the value of the self "Relaying Ability" by the following two steps based on the number of forward nodes and the number of backward nodes. Here, the number of forward nodes is N_f, and the number of backward nodes is N_b.

4.1.1 Step 1: Initial "Relaying Ability" and determination of "Heavy Node" or "Light Node"

At first, each node calculates the initial "Relaying Ability". The difference of the number of forward nodes and the number of backward nodes is set into the initial "Relaying Ability", and it expresses by the following formula. This value expresses the operation situation in that node.

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

In the next processing, the initial "Relaying Ability" is mutually exchanged by each pair of the sideward nodes. And each compares the number of nodes whose "Relaying Ability" is higher than its "Relaying Ability" with the number of nodes whose "Relaying Ability" is lower than its "Relaying Ability". If former number is bigger, the node is called a "Light" node. If latter number is bigger, the node is called a "Heavy" node. This "Heavy" or "Light" label expresses node's relative operation conditions. A example about above mentioned label determination is shown in Figure 7.

4.1.2 Step 2: Updating "Relaying Ability" value of "Light" nodes and routing method

At this step, each node updates its "Relaying Ability" value. For "Heavy" nodes, this type of nodes can not afford a additional data relay, so set 0 to the "Relaying Ability". Each "Light" node updates the self "Relaying Ability" value, and notifies that ability value to the all sideward nodes. Our main load balancing idea is that, "Heavy" nodes should transmit data to "Light" nodes positively, since it can average the power consumption of certain hop area nodes. When a "Heavy" node transmits data to a "Light" sideward node, it will use the "Light" node's "Relaying Ability" value as probability of data transmission.

Each "Light" node inform its "Relaying Ability" to all "Heavy" sideward nodes, and data transmission probability forwarding to a "Light" sideward node will be decided on this value. By

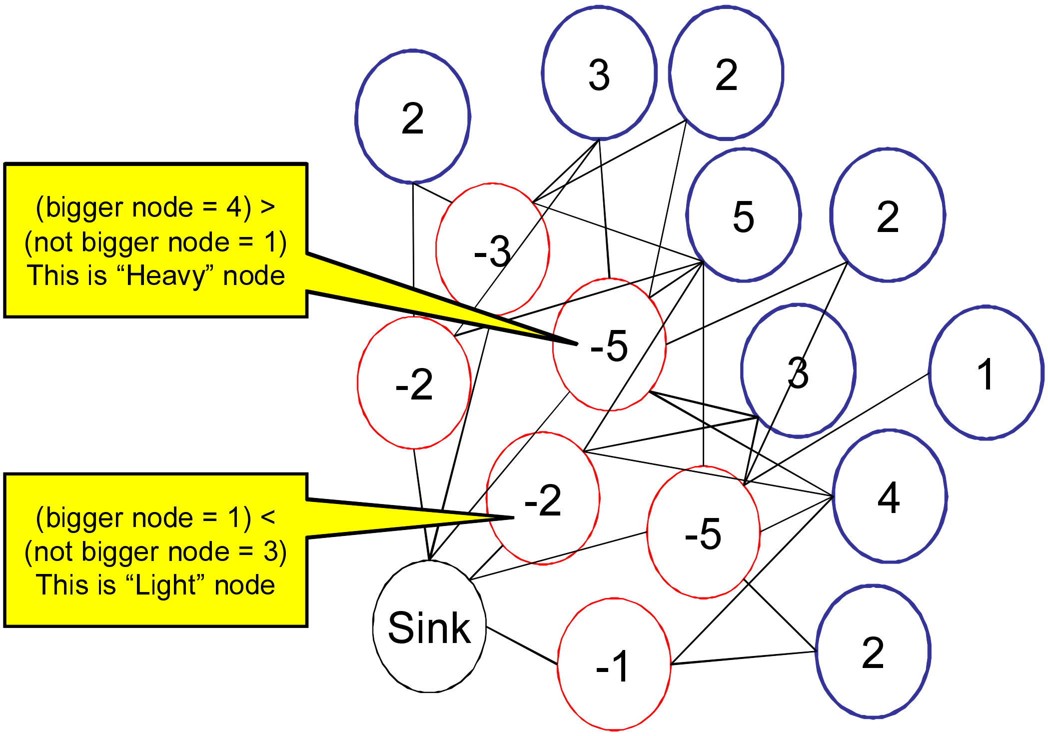


Figure 7: Example of "Light" or "Heavy" node. Red nodes are in hop 1, Blue nodes are in hop 2. Inside number is initial "Relaying Ability" (difference of forward and backward numbers).

blow formula (2), each "Light" node updates the "Relaying Ability" value.

$$RelayingAbility \leftarrow \frac{N_f}{N_{Side}} \cdot \alpha \tag{2}$$

Here, N_f is the number of forward nodes, and it expresses the number of nodes which can receive data transmission from the node. If there are many forward nodes, data can be transmitted easily, but throughput becomes small when there are few forward nodes. Therefore, we think that it should be proportional to the "Relaying ability". N_{Side} is the number of "Heavy" sideward nodes. If this number is large the "Relaying Ability" becomes small, and if this number small the "Relaying Ability" becomes large. Therefore, this number has a relation of inverse proportion to the "Relaying Ability". α is a constant value.

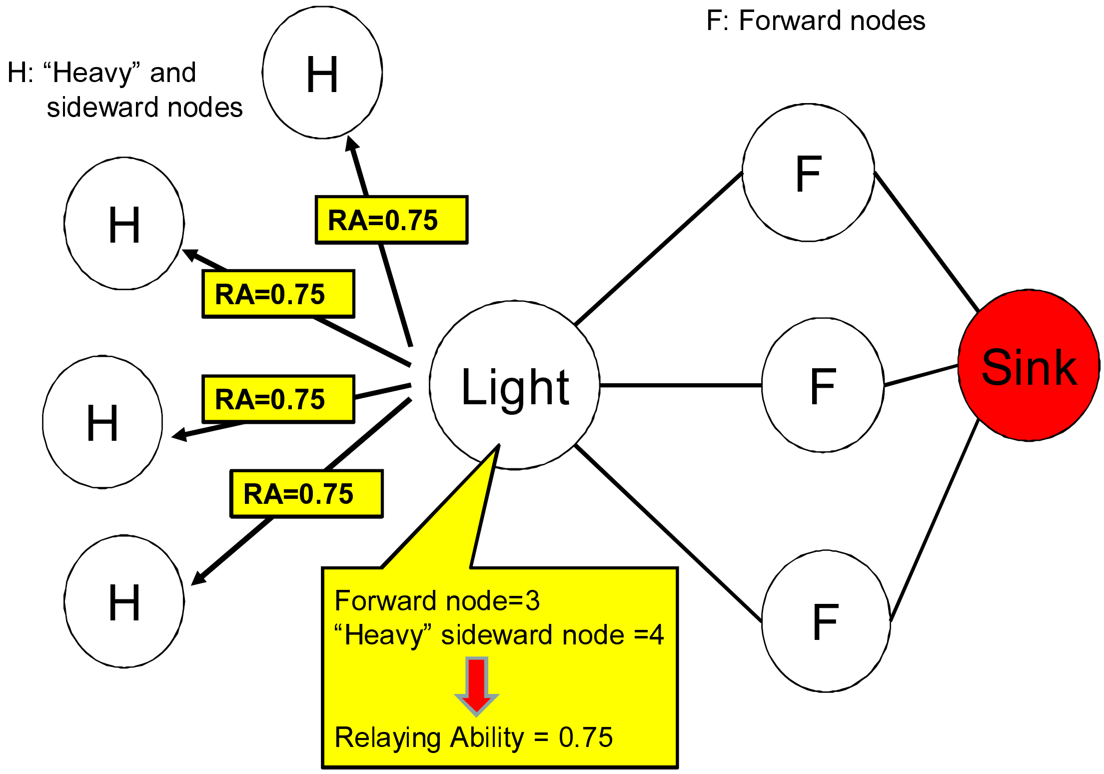


Figure 8: "Light" nodes inform "Relaying Ability" to all "Heavy" and sideward nodes

Data sender node's operation when it is waiting ID from receiver node

- When it receives ID from a forward node, it will send data with probability=1.
- When it receives ID from a sideward node,
  - If itself is "Light" node, it ignore this ID.
  - If itself is "Heavy" node, it will send data with probability=RA_{ID}
- When it receives ID from a backward node, it ignore this ID.

RA_{ID} is ID sender node's "Relaying Ability". The "Light" node which have small traffic transmits only to forward nodes. The "Heavy" node which have big traffic transmits forward nodes and sideward nodes to balance the load.

4.2 Receiver Node Control

Here, we describe the receiver node control. The technique of determining the intermittent interval is also considered as a load distribution technique based on the number of forward nodes, and the number of backward nodes. For such a node which has many backward (large load) and few forward nodes (weak throughput), it consumes lot of power to relay data. Therefore, as for such a node, 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. It becomes equalization of power consumption to increase the number of data receiving. Thus, when it assigns the intermittent interval in consideration of throughput or load between the same nodes, it is possible to equalize the number of times of receiving data.

4.2.1 Step 3: Changing intermittent interval at "Heavy" and "Light" nodes

Here, we propose a technique of determining an intermittent interval using the "Relaying Ability" 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.

- "Light" Node

  A "Light" node raise data relaying frequency more, when the forward node number is still bigger than addition of backward number and "Heavy" sideward number. It means that N_f-forward node number is bigger than addition of N_b-backward node number and N_{Side}-"Heavy" sideward node number. This situation is shown by Figure 9.

  Therefore, it sets up the intermittent interval which is shortened by Formula (3). However, the intermittent interval should be changed with minimum limitation. Because, this limitation make node not to raise data relaying load too much.

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

- "Heavy" Node

  A "Heavy" node sets up longer intermittent interval to lower data relaying frequency, when it does not have sufficient "Relaying Ability" from "Light" sideward nodes and forward node. It means that N_b-backward node number is bigger than the addition of N_f-forward node number and N_{given}-total "Relaying Ability" of "Light" sideward nodes. This situation is shown by Figure 10.

  It longer intermittent interval according to the following Formula (4). However, there is maximum limitation on the changing of intermittent interval. This condition prevents node's relaying frequency becomes too slowly.

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

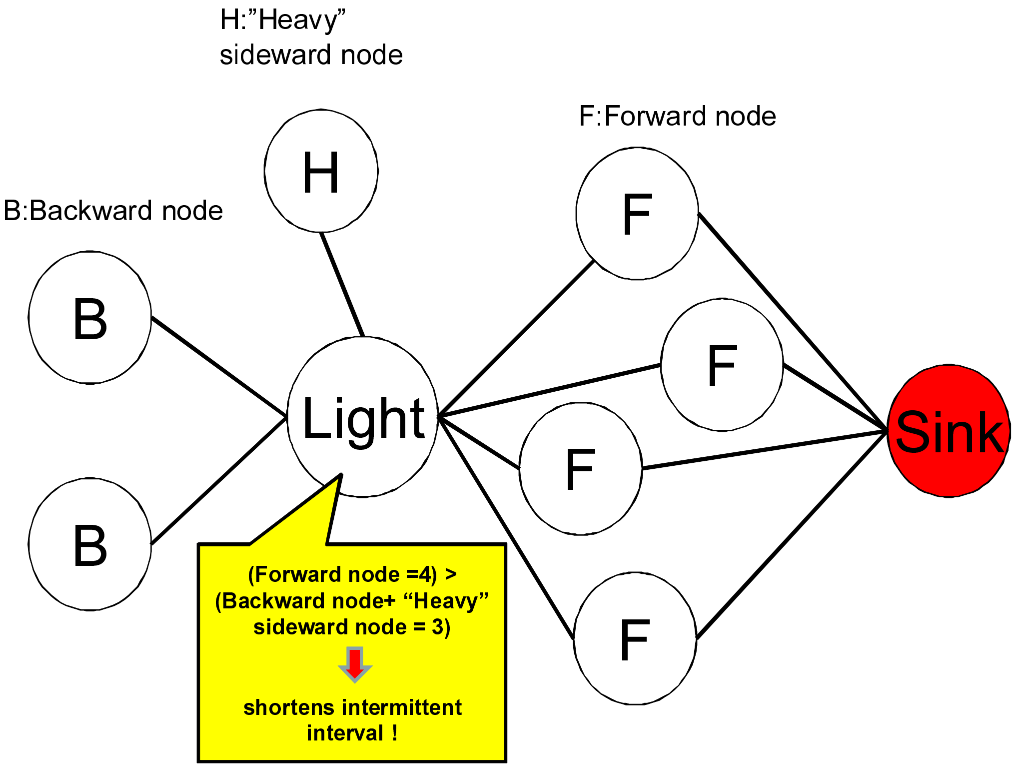


Figure 9: "Light" node shortens the intermittent interval

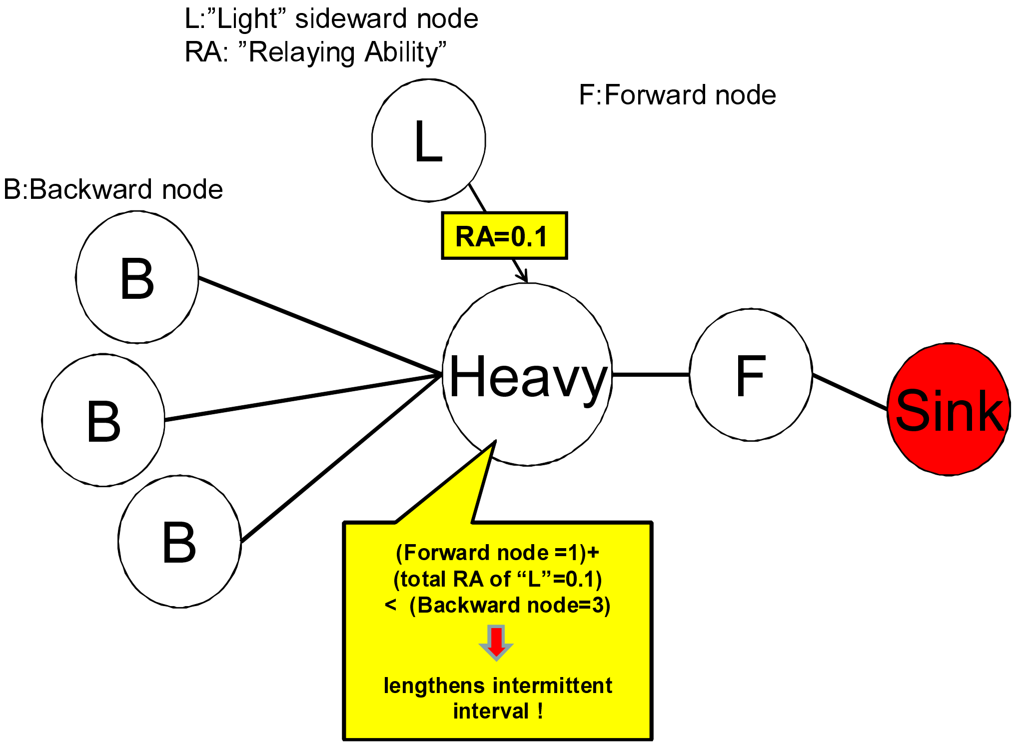


Figure 10: "Heavy" node lengthens the intermittent interval

5 Performance Evaluation

In this section, the performance of the proposal technique is evaluated by computation simulation. First, the simulation scenario is explained. Next, the comparison results of the proposal technique and the existing IRDT system is described. Comparison metrics are network lifetime, average delay, and packet collection ratio. Here, the time until the first node run out battery is determined network lifetime. And the result of consireration of the suitable position of the sink is also described for the apartment type topology which it is currently assumed in this work.

5.1 Simulation Scenario

We assume a simulation network with the topology shown in Figure 11(b). 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. the 119 nodes are between one to six hops away from the sink node, and nodes with the same number of hops are shown in the same color. The detailed information about topology is shown in a Table 2. Our target application is auto gas metering system, therefore we used this grid-like topology which is based on real apartment which shown in Figure 11(a). This apartment has 17 floor and there are seven rooms on each floor. It is assumed that one gas meter has been arranged in each room, and they cooperate mutually and form a network. It is supposed that the height of the room is 3 m and breadth is 4 m. Since almost all of the management office of apartments is on the first floor, the sink node has been deployed on the first floor.

The main parameters of this setup are shown in Table 1. Each sensor node sends it original data packet in average 1000 s time to the sink node. Our system is based on multi-hop routing method, therefore each node relays packets of upper hop nodes.

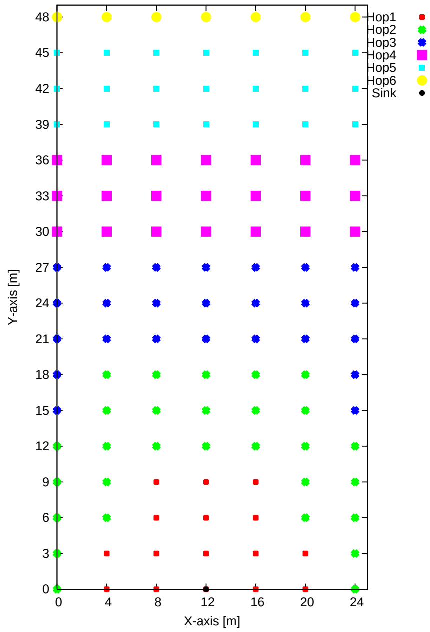
Table 2: Topology Information

Parameter	Value
Node number	119
Sink number	1
Horizontal distance of between nodes	4 m
Vertical distance of between nodes	3 m
Width of topology	24 m
Height of topology	48 m
Transmission range	10 m

Table 1: Simulation Parameters

Parameter	Value
Packet generation rate	0.001 packets/s
Initial battery ability	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

(a) The assumet aparment



(b) Logical topology:nodes in same color have same hop number

Figure 11: Simulation Topology

5.2 Numerical Results

In this section, we describe the simulation results and those considerations. The existing technique IRDT, and the proposal technique are compared by simulation method. Comparison metrics are power consumption, network life, delay time, and a packet collection ratio. From next section, the result about these metrics is described respectively.

5.2.1 Results about power consumption and network lifetime

Here, the comparison result about the power consumption of the proposal technique and IRDT is described. According to the situation of topology, the difference of load occurs between the nodes with the same number of hop. The amount of consumed0 power on a ”Heavy” node is increasing the existing IRDT system in comparison in order to perform the routing technique only depending on the number of hop, without taking such a difference into consideration. Also when the number of hop is the same, that average consumption power changes greatly with ”Light” or ”Heavy” can see from figure 12(b). In the case of the proposal technique, since a ”Heavy” node transmits much traffic to a sideways ”Light” node by load balancing and also the intermittent interval is also controlled according to a situation, it can check from this figure that power consumption of these nodes is balanced.

Therefore, since the power consumption between the nodes with the same number of hop was equalized by the proposal technique, Figure 12(a) shows the result that the network lifetime was extended. Moreover, when the packet generation ratio per node is raised, it is shown how the network lifetime is changing in this figure. With increase of network load, the network lifetime has fallen, but the proposal technique has longer network lifetime than IRDT.

5.2.2 Results about delay time

Here, the comparison result of the average delay time in the proposal technique and IRDT system are described. Figure 13(a) shows change of the average packet delay time when a packet generation ratio is increasing. From the result, It can see that average delay time in the proposal technique smaller than compared with IRDT. Furthermore, even if network load increases, only a few amount is increasing average delay time. However, in the case of the IRDT system, it is increasing more quickly. To be jammed of ID reception waiting will occur and it will require time for data transmission, when traffic increases. Since sideward nodes is positively used in the proposal technique even if traffic increases, it can be said that the proposal technique has load tolerance more than IRDT.

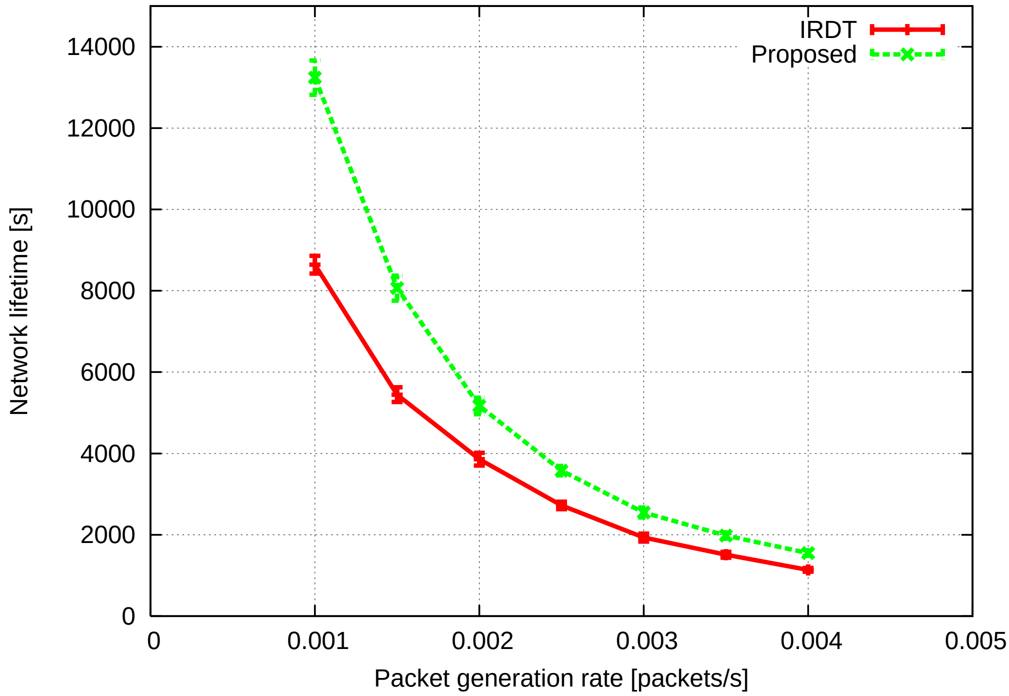
The comparison result of the average delay time to the sink arrival in each hop is shown in Figure 13(b). Since it increases to the number of times of relay in connection with the number of hop increasing, average delay time is increasing. In the hop 1, the sink is directly connected and there is no difference in delay time not much. After the hop 2, it can confirm that delay time is smaller in proposal technique. In a ”Heavy” node, since it can transmit to the sideward nodes at an early stage by the proposal technique, increases of the delay time by ID waiting time are reducible. In a ”Light” 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. Therefore, the proposal technique has improved the IRDT system in average delay time.

5.2.3 Results about packet collection ratio

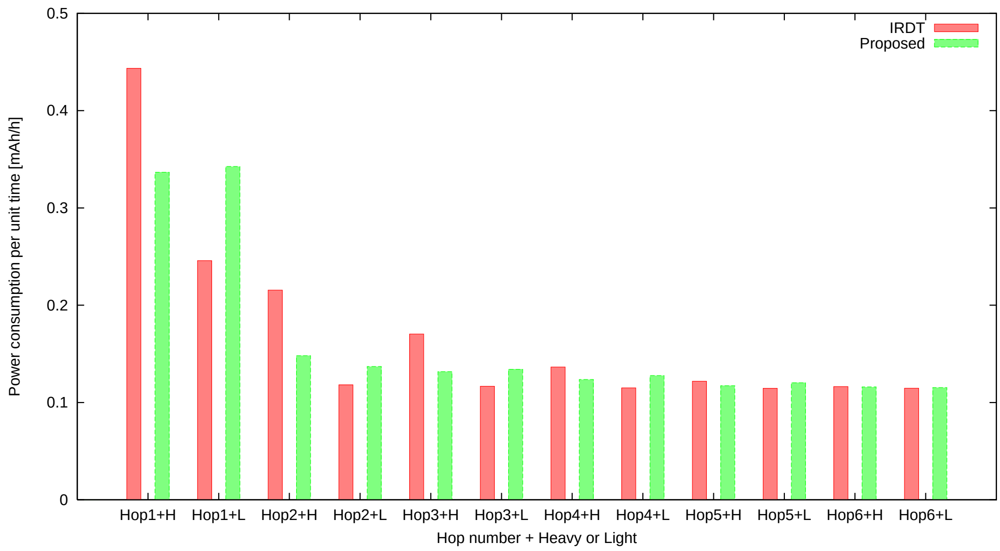
Here, the comparison result about the packet collection ratio in the proposal technique and IRDT system are described. When the packet generation ratio per node is raised, it is shown in Figure 14(a) how a packet collection rate changes. It turns out to the increase in network load that the packet collection ratio is falling in two systems. Since packet collision and hidden terminal problem probability will increase if traffic increases, as a result the packet collection ratio falls.

The comparison result of the average packet arrival ratio in each hop is shown in Figure 14(b). It is confirmed that the proposal technique and IRDT system can maintain a certain packet arrival ratio at each hop and each node. However, in the proposal technique, the packet collection ratio is doing the abbreviation 3% fall of.

The reason is that the probability of the packet collision having go up with the proposal technique as a result of the increase of traffic of the ”Light” 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. In our simulation, network load was very close to the limited range. Then, apply to our method on existing IRDT, hop 1 area’s communication frequency has gone over the limited range. Therefore , addition 3% of packet drop ratio emerged at hop 1’s “Light” nodes. As solution methods against this problem, the addition of a back-off function and reduction of network load can be considered. It is proved that the back-off function improves significantly the packet collection ratio by our precedence research.

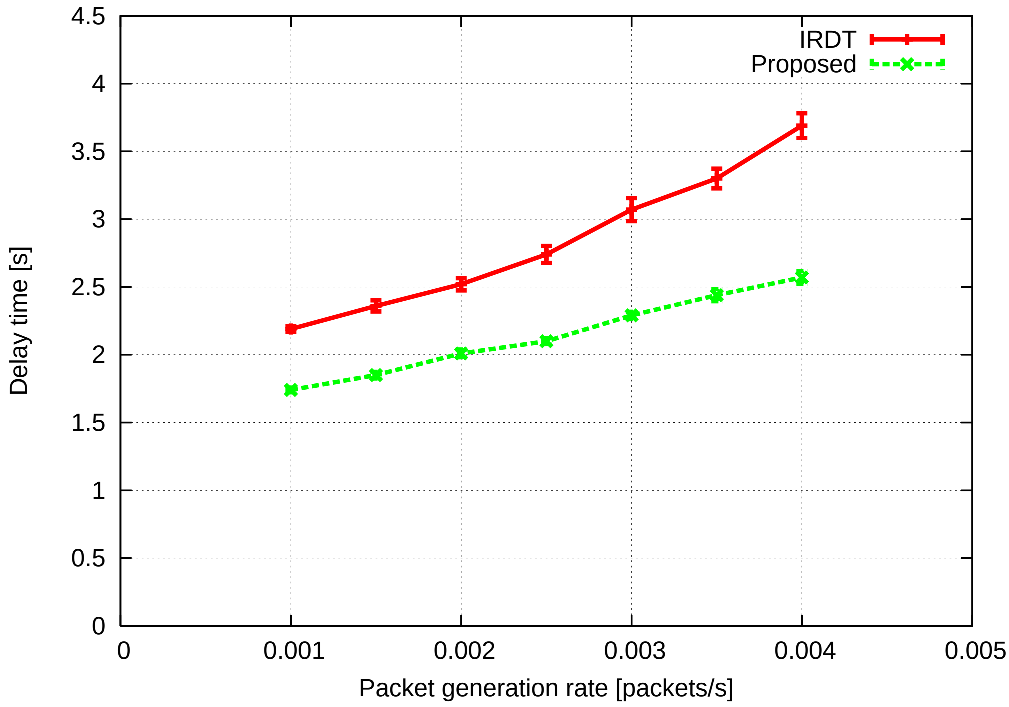


(a) Comparison result of network lifetime

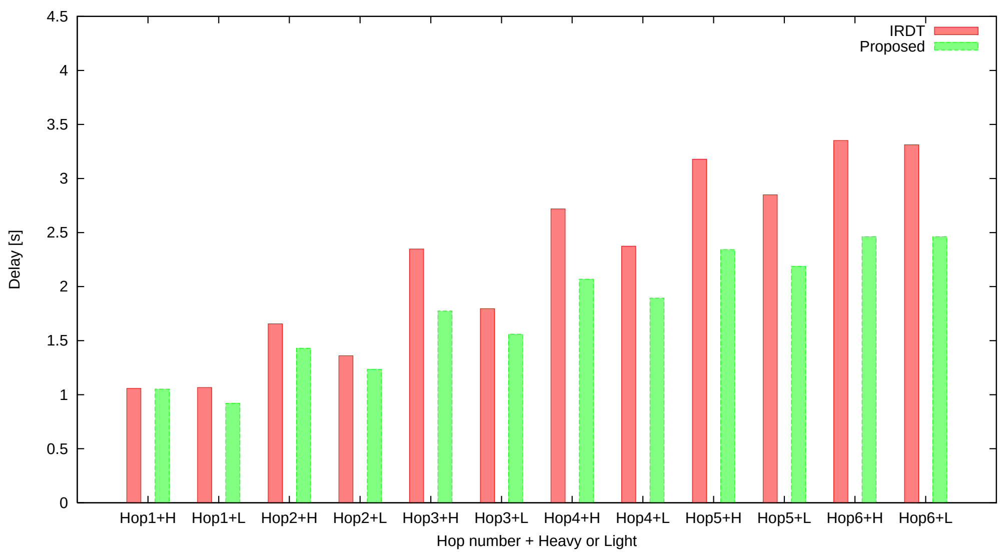


(b) Average power consumption at each hop

Figure 12: Comparison of power consumption performance

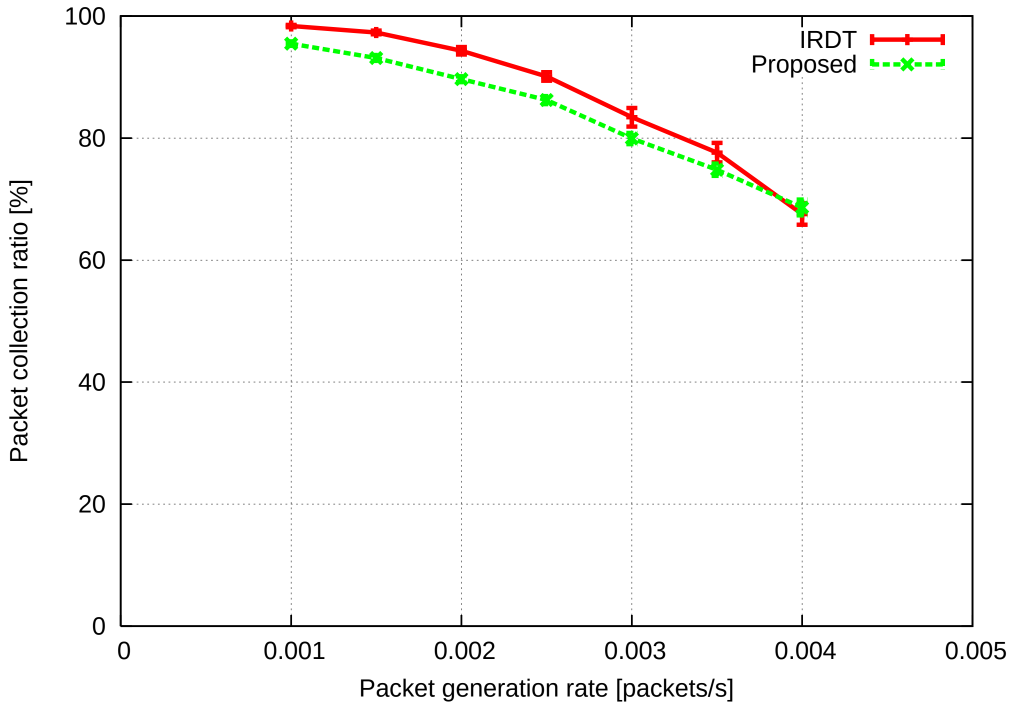


(a) Comparison result of delay

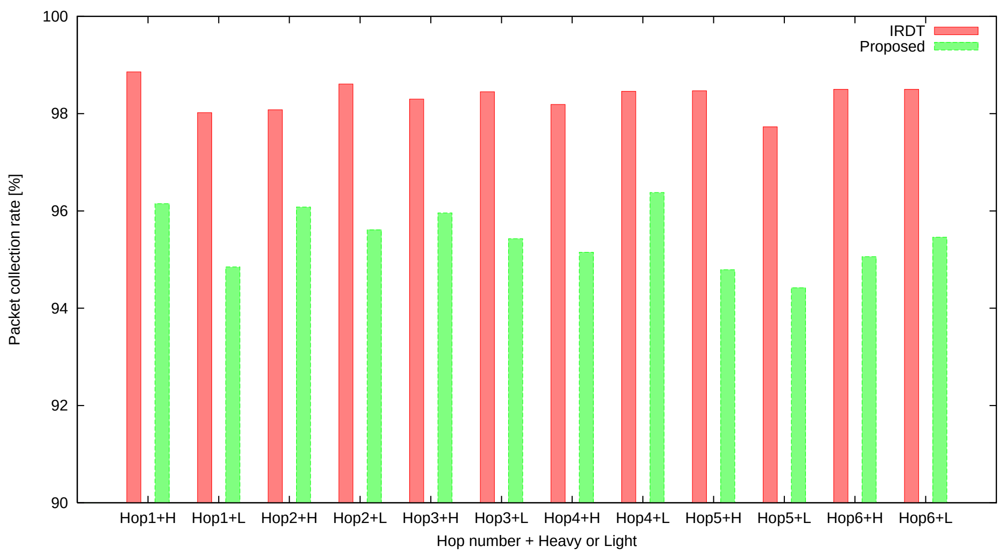


(b) Average delay time at each hop

Figure 13: Comparison of average delay performance



(a) Comparison result of packet collection ratio



(b) Average packet collection ratio at each hop

Figure 14: Comparison of packet collection ratio performance

6 Conclusion

In this thesis, we proposed load balancing techniques for the receiver-driven asynchronous system IRDT, when the topology is dense or communication range is long enough. 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. There was 3% of packet drop ratio comparing with existing IRDT, because of the increase in traffic at hop 1 nodes. As solution methods against this problem, the addition of a back-off function and reduction of network load can be considered.

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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