An Evaluation of the Influence of Communication Metrics in Realizing Multi-path Routing in Consideration of the Communication Situation on an Ad hoc Network

Yuki Asanuma*, Yoshitaka Nakamura** , and Osamu Takahashi**

*Graduate School of Systems Information Science, Future University Hakodate, Japan
**School of Systems Information Science, Future University Hakodate, Japan
{g2114001, y-nakamr, osamu}@fun.ac.jp

Abstract - In recent years, with the development of wireless technologies, ad hoc networks, which are formed without any central administration and consist of mobile terminals, have begun to be used in a variety of applications. Clustering is one of the techniques useful for ad hoc network routing, because clustering techniques can manage wireless communication terminals hierarchically in an ad hoc network. The technique of routing using clustering can create a communication path which realizes stable communications. Furthermore, routing using Cluster-by-Cluster technique, which is an extension of Clustering, can improve packet arrival rate and reduce routing overheads. However, Cluster-by-Cluster routing does not respond to changes in the communication state. Therefore, there is a problem in that overall network throughput decreases in the network environment where there are multiple communications. In this paper, we propose a flexible route selection method to improve the overall network throughput. We also evaluate the influence of various network metrics based on traffic amount in our method.

Keywords: Ad hoc network, Clustering, Traffic. Path switching, multiple communications

1 INTRODUCTION

In recent years, the use of ad hoc networks has spread due to the progression of wireless communication and increasingly high performance of devices. Ad hoc networks do not need infrastructures such as base stations. Additionally, an ad hoc network will autonomously form a wireless terminal network. The reactive protocols DSR (Dynamic Source Routing) [2] and AODV (Ad hoc On-Demand Distance Vector) [3] are well-known routing protocols used on ad hoc networks. With these routing protocols, as the data communication path becomes longer, there is a decrease in the packet arrival rate and an increase in the routing overhead. Therefore, long communication paths cause congestion on ad hoc networks when there are multiple communications. As a result, communication reliability decreases. Thus, in order to realize stable communications, it is necessary to suppress the occurrence of long-path communication. Routing using clustering is an effective method in this case [4]. Clustering is used to form a group of physically close nodes on the network. This group is called a cluster. Clustering can streamline processes, such as the building of routes at the time of communication, more effectively than Non-cluster-based routing. In respect to this cluster-based routing, Cluster-by-Cluster routing [5] has further improved the suppression of long communication paths. Cluster-by-Cluster routing is able to generate and combine multiple fresh short paths by utilizing the mechanism of the route cache. Thereby, the method has solved the issues of reduction in packet arrival rate and increase of the overhead caused by long-path communication. However, Cluster-by-Cluster routing continues to use one path from the start of communication until the end and has no mechanism by which to switch paths. The communication status of nodes will change at any time on a network on which multiple communications exist. Consequently, the throughput is reduced due to communication congestion and increase in traffic.

In this paper, a path-switching mechanism is added to Cluster-by-Cluster routing in order to maintain the throughput of the entire network, for networks on which multiple communications exist. We selected effective metrics for the path-switching mechanism and evaluated their effect on these networks using the network simulator ns-2.

2 RELATED WORK

2.1 Cluster-by-Cluster Routing

Cluster-by-Cluster routing builds an overlay network on a cluster in addition to the recorded path relay node present in a normal ad hoc network. It performs routing between clusters on the overlay network. Fig. 1 shows an example of Cluster-by-Cluster routing.

Cluster-by-Cluster routing forms a cluster of physically close nodes around a central node called the CH (Cluster Head), in the same manner as typical cluster-based routing. Every cluster has one CH which centralizes the information of the nodes in the cluster. Also, when communicating with different clusters, the CH will designate the node located at the border between clusters as a CG (Cluster Gateway), which is used to bridge the communications between clusters. Nodes other than the CH and CG are set as MN (Member Node).

When carrying out data communication between nodes, the communication travels cluster-by-cluster from the source node cluster to the destination node cluster (Fig. 1). Thereby, Cluster-by-Cluster splits the long path from the source node to the destination node into multiple short paths at a unit of one cluster (Fig.2 and 3).

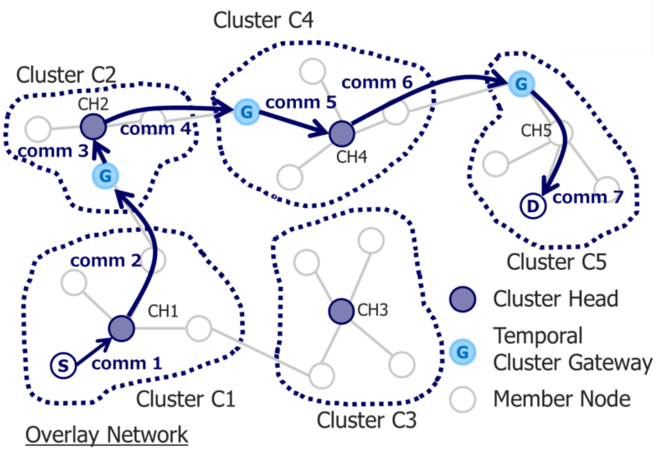

Figure 1: Cluster-by-Cluster routing

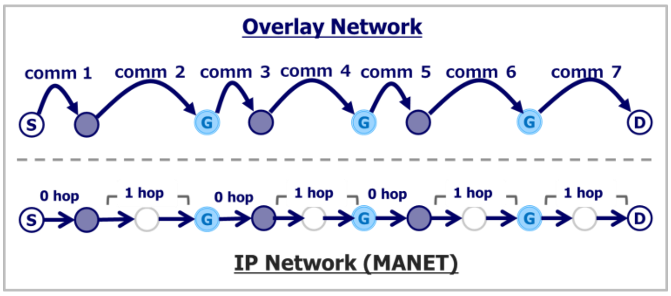

Figure 2: The communication division in Cluster-by-Cluster routing

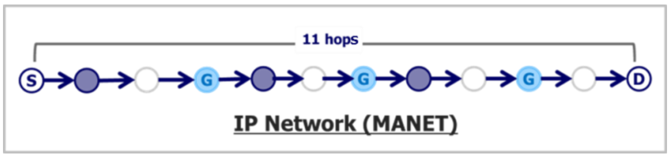

Figure 3: Communication path of traditional routing

2.2 Cluster-by-Cluster Routing Considering Adjacent Terminals

Cluster-by-Cluster routing is assumed to be used on a network which has a large number of nodes. However there is a case in which multiple communications exist, creating a risk that one communication may decrease the performance of other communications. To solve this problem, a route-switching function that makes use of certain network metrics was applied to Cluster-by-Cluster routing, thus creating Cluster-by-Cluster routing that considers the adjacent terminals[6]. In this approach, the number of adjacent terminals $\boldsymbol{N}$, average link cutting estimated time level $\boldsymbol{LLT}$, battery power $\boldsymbol{B}$, and the behavior of the node $\boldsymbol{T}$, are used in the following formula, to calculate the priority-level of a path.

$$\boldsymbol{W} = \boldsymbol{\omega_1} \times \frac{\mathbf{1}}{\boldsymbol{N}} + \boldsymbol{\omega_2} \times \frac{\mathbf{1}}{\boldsymbol{LLT}_{\boldsymbol{average}}} + \boldsymbol{\omega_3} \times \frac{\mathbf{1}}{\boldsymbol{B}} + \boldsymbol{\omega_4} \times \frac{\mathbf{1}}{\boldsymbol{T}_{\boldsymbol{role}}} \quad (1)$$

The priority $\boldsymbol{W}$ figures obtained for each path are compared and the route is switched dynamically to the path with the largest value of $\boldsymbol{W}$. As a result, the overall load of the network is dispersed, thereby improving throughput.

3 PROPOSED METHOD

3.1 Positioning of This Research

In this paper on a path-switching function using multiple metrics for Cluster-by-Cluster routing, we will evaluate the effect of each metric on ad hoc networks that do not form clusters. The proposed method was created with the original premise of forming clusters, but in this paper, as befits the circumstances of the experiment, cluster-formation is not covered.

3.2 Cluster-by-Cluster Routing for Performing Path Switching by Using the Traffic Situation in the Metrics

The Cluster-by-Cluster routing [7] proposed in previous studies by the authors of this paper (hereinafter, the proposed method), performs path-switching using the following three steps:

(1) Collection and measurement of metrics
(2) Calculation of priority of paths
(3) Switching of path

Cluster-by-Cluster routing is built based on the DSR, and can only build and maintain a single path. The proposed method extends the Cluster-by-Cluster routing by creating one primary path and two alternative paths. Generally, DSR only holds the path which RREP arrived at earliest, but the proposed method expands DSR and allows to hold paths which RREP at after the second. We assume the path which RREP arrived at earliest as the primary path and assume the path which RREP arrived after the second as the alternate paths. By switching pathways in response to the situation, this system stabilizes routing. For path-switching, the metrics needed to maintain the throughput are essential. The proposed method uses four metrics (the number of hops, the amount of traffic, link status and battery level) for path-switching.

After measuring the metrics at each node, the Neighbor Feedback with which Cluster-by-Cluster routing is equipped is used to pass metrics information to the source node. The proposed method uses Neighbor Feedback to transmit a beacon, to which metrics information has been added, from each node to the source node.

The metrics of number of hops are calculated using the 'hop count' function of the RREQ (Route Request). If movement of the nodes has caused the MN and the CG to move to a place where communication is impossible, the number of hops will change dynamically in Cluster-by-Cluster routing. However, this paper does not take into account the change in the number of hops, because the nodes are fixed. As for traffic, each node refers to its own queue to examine the amount of packet being held, and then saves that amount as $\boldsymbol{traffic}$. Generally, the link state refers to the communication delay time between adjacent nodes. $\boldsymbol{Link}$ is the average delay time per hop, calculated by dividing the communication delay time by the number of hops of a communication path. Each node saves its own battery power as $\boldsymbol{B}$.

The source node calculates the priority $\boldsymbol{W}$ for each path based on the collected metrics, and uses this data as path selection criteria. $\boldsymbol{W}$ *is* calculated using the following formula:

$$\boldsymbol{W = \omega_1 \times \frac{1}{N} + \omega_2 \times \frac{1}{traffic} + \omega_3 \times \frac{1}{Link} + \omega_4 \times B} \quad (2)$$

Here, the number of hops $\boldsymbol{N}$ is from the source node to the destination node, $\boldsymbol{traffic}$ is the sum of the traffic of each node in the corresponding path, and $\boldsymbol{Link}$ is the average delay time per hop between nodes in the corresponding path. $\boldsymbol{B}$ represents the average amount of remaining battery of the node in the corresponding path. In addition, each of the metrics is weighted by parameters from $\boldsymbol{\omega_1}$ to $\boldsymbol{\omega_4}$. By using these metrics, it is possible to consider the communication situation for a certain network easily, and to decide which metrics are most important for the network. Path switching is performed based on the flowchart depicted in FIG4. In the proposed method two types of path exist. The first is the primary path which communicates the packet to the destination node in response to the transmission request of the source node. The second is the alternative path, of which one or more will be constructed to act as potential candidates for the path-switching. At fixed times, the source node calculates the priority $\boldsymbol{W}$ of all the paths, primary and alternative. After the calculation, it sets the path with the largest value of $\boldsymbol{W}$ as the primary path and uses this path at the time of communication. If none of the primary and alternate paths is available, the source node once again sends a transmission request, to reconstruct the communication path (Fig. 5).

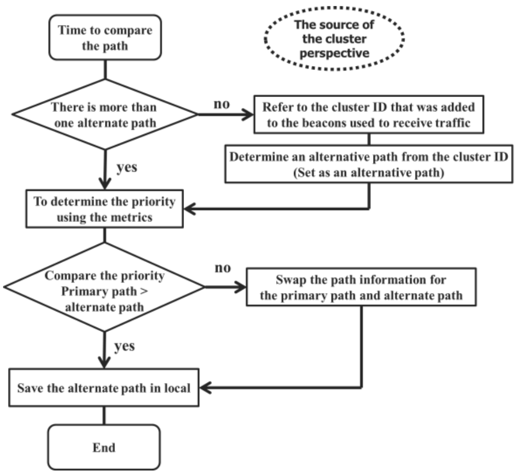

Figure 4: The path switching algorithm by priority

3.1 Metrics Based Strategy

In general, the number of hops from the source node to the destination node influences the throughput. However, the number of hops alone cannot respond to a case in which multiple communications are present, resulting in a decrease in throughput due to communication congestion caused by the concentration of traffic on a specific path. Consequently, it is believed possible to prevent a decrease in throughput by including the traffic amount in the metrics. This is because even if multiple communications are present, the concentration of communication on a specific path is prevented. Furthermore, the throughput is lowered when a communication delay is caused by various problems with the nodes. In this case, it is possible to prevent a decrease in throughput by creating a communication path that does not pass through any nodes in which communication delay is occurring. This communication delay is referred to as a link state and used as metrics. Nodes consume battery during communication and therefore is possible that the continuation of communication will become impossible if the residual battery amount is significantly reduced. In this case, the communication is disconnected to cause a reduction in rapid throughput. By considering metrics of remaining battery amount, it is possible to avoid using nodes with low remaining battery capacity, and thus long-term communication becomes possible [8].

4 SIMULATION RESULTS

4.1 Experiment

We conducted evaluative experiments to investigate the effect of routing using the metrics, in the network simulator ns-2(Network Simulator version 2) [9]. The simulation parameters are shown in Table 1.

This experiment was carried out on an ad hoc network with fixed nodes without forming clusters, in order to investigate the effect of the metrics on the network. However, in this experiment the destination node was configured to transmit a beacon message to convey each type of metrics information to the source node, in the same way as Cluster-by-Cluster routing. If the remaining battery power of the source and destination nodes is zero,

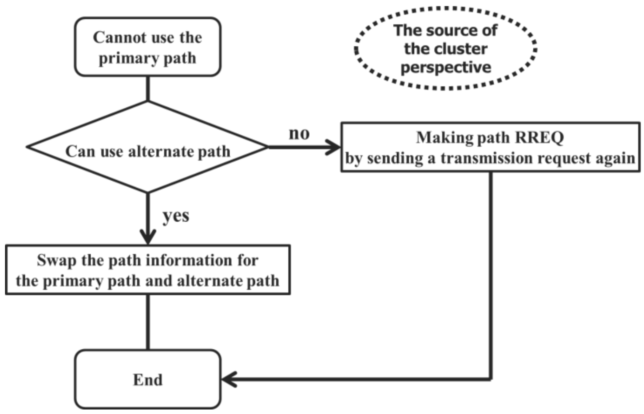

Figure 5: If the primary path and alternate paths are not available

communication becomes impossible regardless of the communication path. Therefore, the battery capacity of the source and destination nodes was twice that of the other nodes, to ensure that communication would not be interrupted during the experiment. The topology of the experiment is as shown in Fig. 6, with communications A, B and C shifting in time on the topology. Thereafter, it calculates priority $\boldsymbol{W}$ and switches to a path based on this. Priority $\boldsymbol{W_1}$ and $\boldsymbol{W_2}$ and $\boldsymbol{W_3}$ and $\boldsymbol{W_4}$ were determined in Experiments 1, 2, 3 and 4 as follows:

Experiment 1 : $\boldsymbol{W_1 = \omega_1 \times \frac{1}{N}}$ (3)

Experiment 2 : $\boldsymbol{W_2 = \omega_1 \times \frac{1}{N} + \omega_2 \times \frac{1}{traffic}}$ (4)

Experiment 3 : $\boldsymbol{W_3 = \omega_1 \times \frac{1}{N} + \omega_2 \times \frac{1}{traffic} + \omega_3 \times \frac{1}{Link}}$ (5)

Experiment 4 : $\boldsymbol{W_4 = \omega_1 \times \frac{1}{N} + \omega_2 \times \frac{1}{traffic} + \omega_3 \times \frac{1}{Link} + \omega_4 \times B}$ (6)

Communication A communicates from 100s to 1200s. Communication B communicates from 500s to 1500s. Communication C communicates from 700s to 1400s. In all the experiments, calculation of priority and switching of path occurs at 750s. Table 2 shows the parameters relating to communication.

Table 1: Simulation parameters

Measurement time (seconds)	1500s
Network size	1200m × 1200m
Number of nodes	36
Communication protocol	UDP
Routing protocol	DSR

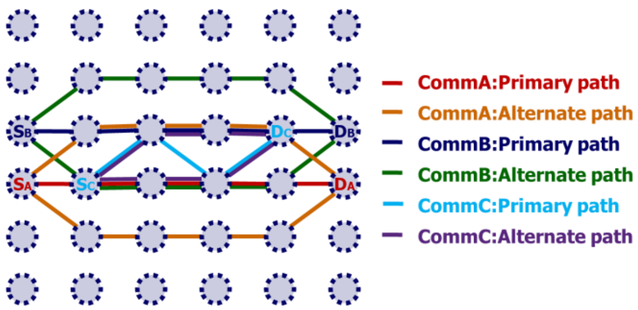

Figure 6: Topology of the experiment

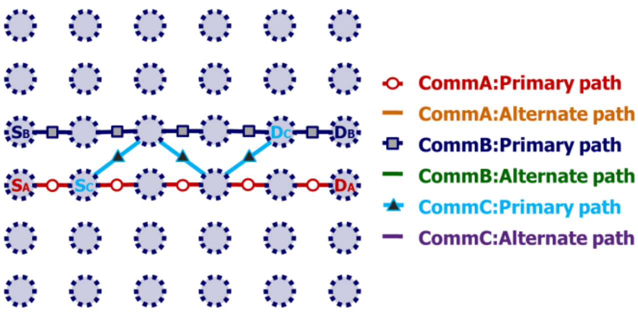

Figure 7: Experiment 1: Communication path

4.2 Experiment Results and Discussion

Results of path-switching in Experiment 1 and the communication paths are shown in Fig.7, and the throughput fluctuations of the entire network are depicted in Fig. 8. Priority $\boldsymbol{W_1}$ for path switching does not consider the number of hops. Therefore, it exhibited the same behavior as regular DSR in this experimental environment where the number of hops does not change. As a result, the path could not be switched, the throughput of the entire network was greatly reduced and communication became congested after 750s. Communication became impossible at 1000s because the remaining battery amount of the nodes used by communication A and communication C became zero. Therefore, communication B recovered throughput in 1000s and maintained a substantially constant throughput up to 1500s.

$\boldsymbol{W_2}$ has traffic added to the number of hops as metrics. We were using $\boldsymbol{W_2}$ as the priority value of Experiment 2 for path-switching. Figures 9 and 10 show the results of Experiment 2. The results reveal that path-switching was possible when the number of hops and traffic amount were considered. This is because communication could use a well-balanced selection of nodes, rather than being concentrated on fixed nodes. However, communication was temporarily disconnected for a moment when path switching and the throughput was drastically reduced. Communication A in Experiment 1 was disconnected due to low battery. However, in Experiment 2 communication became possible at 750s because the communication path switched to the alternative path. From this result, it can be seen that it is possible to carry out prolonged communication even without using remaining battery amount metrics, by using path-switching to communicate across multiple different nodes, in particular environment.

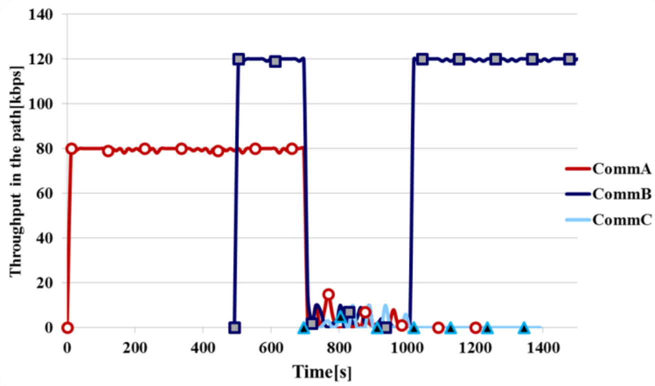

Figure 8: Experiment 1s: Throughput on path

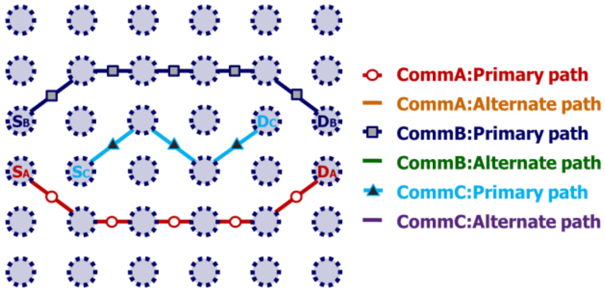

Figure 9: Experiment 2: Communication path

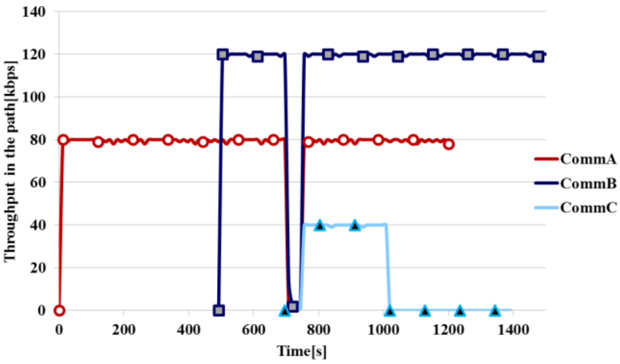

Figure 10: Experiment 2: Throughput on path

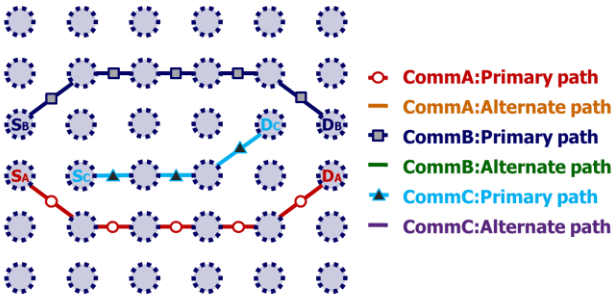

Figure 11: Experiment 3: Communication path

W_3 had link state added to the pre-existing metrics of number of hops and traffic volume. We used W_3 as the priority value of path-switching in Experiment 3. Fig. 11 and Fig. 12 show the results of Experiment 3. The results show that communication A and communication B did not change, but the communication path of communication C did change. The notes being set in a grid formation, DSR control messages arrived at vertically or horizontally adjacent nodes faster than diagonally adjacent nodes, due to the slightly longer distance in this direction. Despite this, looking the results in Fig. 12, it can be understood that there was no change in throughput when compared to Experiment 2. This is most likely because this experiment did not take into account the performance differences of each node and UDP communications were carried out in environments where there were no obstacles such as interference. Thus, the link state can be expected to be effective in environments where there exists a shield between the nodes, or physical performance of each node is different.

W_4 had remaining battery power added to the three aforementioned metrics. We used W_4 as the priority value in Experiment 4. Fig. 14 and Fig. 15 show the results of this experiment. Similar to Experiment 3, both the the

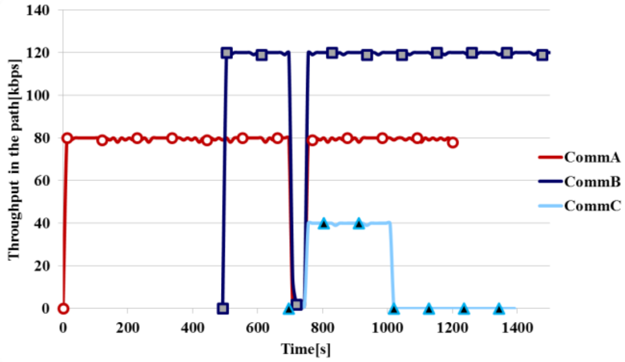

Figure 12: Experiment 3: Throughput on path

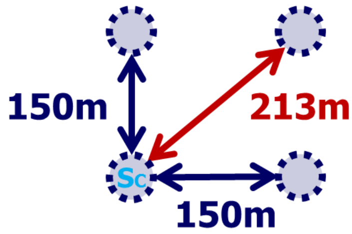

Figure 13: Distance between nodes

communication path and throughput of communication C changed. The communication path was been switched to a path with greater remaining battery power. As a result, the throughput of communication C did not decrease even after 1000 seconds, unlike in Experiment 3. The relay node used by communication C in Experiment 3 was used by communication A after 10 seconds, meaning that the remaining battery amount was lower than that of other nodes. It is expected that were communication C to continue to use nodes with little remaining battery capacity, the battery power would eventually become zero, causing the throughput to rapidly decrease. Using metrics of remaining battery capacity worked effectively to alter the route of communication C to pass through nodes with a large amount of remaining battery. In this way, reduction of communication throughput was prevented and the throughput of communication C is considered to have improved after 1000s.

Finally, the graph in Fig. 16 summarizes the throughput of the entire network in Experiments 1, 2, 3, and 4. The results confirm that when the amount of traffic is included in the metrics, the entire network throughput is improved and benefits from the effect. Furthermore, the remaining battery amount was also found to be necessary metrics in the case of long-term communication. However, link-state metrics did not work effectively and were not suitable for the assumed network environment. It is considered that these metrics would be effective in situations where there is an obstacle between nodes and a difference in the performance of each node, or where, as in MANET [10], the nodes move and the strength of the radio waves that nodes can receive is constantly changing. Through all of the experiments, the overall throughput is seen to fluctuate slightly. This is a result of the effect of the metrics collection beacon, and it is possible that the throughput may decrease further in a large network with many nodes.

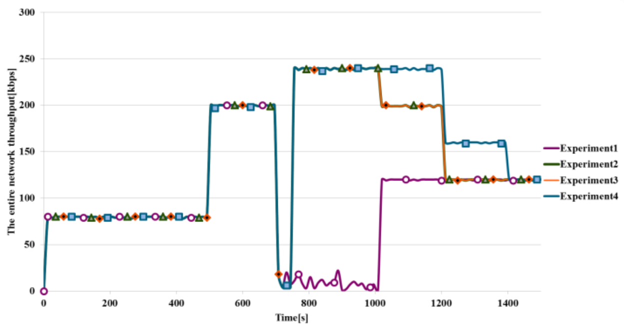

Figure 16: Overall network throughputs of Experiment 1-4

5 CONCLUSION

In this paper, we used the network simulator ns-2 to evaluate the influence on the network of adding a path-switching function to Cluster-by-Cluster routing. We confirmed that improvement of throughout of the entire network can be achieved by combining four metrics (number of hops, amount of traffic, link state and remaining amount of battery). In the future, it is necessary to evaluate whether the proposed method is effective in a network in which clusters are formed.

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