Node repositioning method based on topology information in IEEE 802.16j relay networks

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***Abstract*—IEEE 802.16j relay networks can provide wide-area wireless broadband service. In these networks, the locations of relay nodes and the topology are important factors in achieving high performance. In particular, radio wave interference must be considered when establishing node locations. However, nodes are generally deployed in limited areas and cannot be moved to arbitrary positions. In this paper, we propose a node repositioning method that works within these constraints to improve network performance and that utilizes only topology information. Since the computational cost is high for assessing all possible node positions, the proposed method limits the number of candidate nodes to be repositioned on the basis of topology information. We examine the effectiveness of the proposed method through simulation experiments and show that a performance improvement of up to 28% is realized and nearly optimal results are obtained, but at much lower computational cost than an exhaustive search.**

Keywords*- *IEEE 802.16j; relay network; node repositioning; network performance improvement.

I. INTRODUCTION

Wireless relay networks based on IEEE 802.16j [1] are now attracting considerable attention since they can provide wide-area network service at a low cost to metropolitan areas or areas in which the construction of wired networks is difficult [2]. An IEEE 802.16j network consists of two types of nodes: gateway nodes and relay nodes [3]. A gateway node is wired to an external network. On the other hand, a relay node is not directly wired to the external network and instead connects via wireless links that form a multi-hop relay network whose root is the gateway node (Figure 1). One advantage of this type of network is that the service area can be extended easily and the network capacity can be increased by adding relay nodes [4].

In wireless networks, a general problem is that communication links that interfere with each other cannot communicate at the same time [5], [6]. IEEE 802.16j networks solve the radio wave interference problem by adopting the Orthogonal Frequency Division Multiple Access (OFDMA) scheme [7], which is a scheduling mechanism based on the Time Division Multiple Access (TDMA) and FDMA schemes [8]. In this scheduling method, time slots are assigned to each communication link as transmission opportunities according to its traffic demands. The links that interfere with each other use different time slots and the links that do not interfere with each other use the same time slots to increase spatial reuse of radio resources [9], [10]. To decrease the number of assigned time slots is important for achieving high performance in these networks and radio wave interference must be taken into account when positioning the nodes to reduce the number. In general, however, nodes are deployed in limited areas and cannot be moved to arbitrary positions. An example is shown in Figure 1, where nodes are set up on the roofs of buildings in an urban area and a node can be moved within only the roof area.

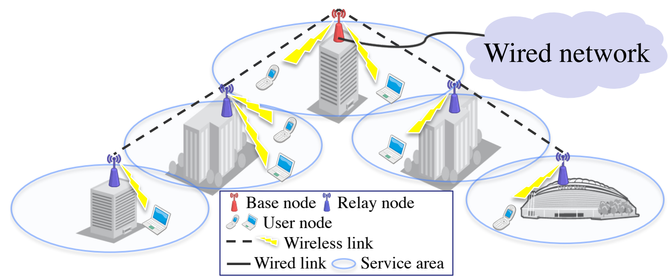

Figure 1. IEEE 802.16j relay network

In this paper, we propose a node repositioning method that works within such constraints to improve the performance of IEEE 802.16j relay networks. Our proposed method utilizes only topology information to determine which nodes are repositioned. Furthermore, we limit the number of nodes to be repositioned since the computational cost is high for assessing all possible node positions.

We evaluate the effectiveness of the proposed method through simulation experiments where the number of time slots assigned to all links in the network is taken as the assessment criterion. We also show the results of evaluating

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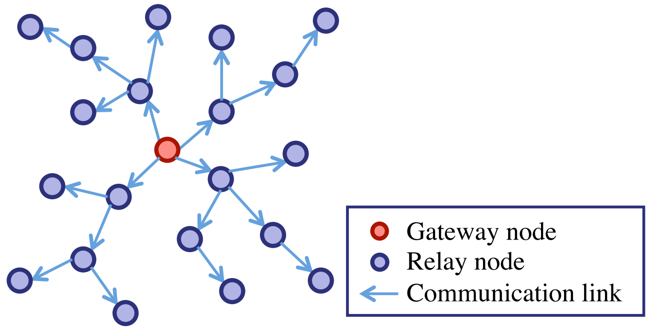

Figure 2. Network model

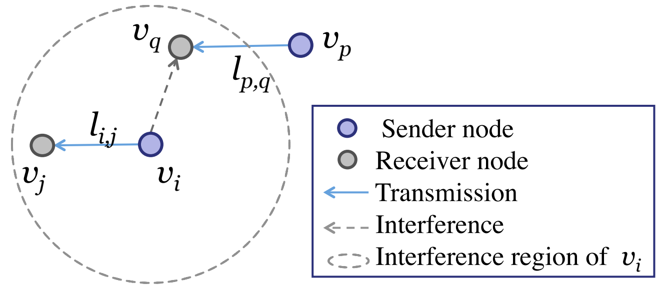

Figure 3. Radio wave interference model

computational cost.

The rest of this paper is organized as follows. In Section II, we explain the network model and the time slot assignment algorithm. Then, we propose the node repositioning method in Section III. In Section IV, we evaluate the effectiveness of the proposed method through simulation experiments. Finally, we present the conclusions of this paper and areas of future research.

II. System Model

In this section, we describe the IEEE 802.16j relay network model, radio wave interference model, and time slot assignment method which we employ in this study.

A. IEEE 802.16j relay network model

The network model consists of one gateway node and multiple relay nodes. These nodes form a multi-hop relay network whose root is the gateway node (Figure 2). The network topology is constructed such that all relay nodes reach the gateway node via the minimum number of hops. After determining the topology, each node sets its own transmission range to the minimum value for maintaining its link. This adjustment of transmission range helps in reducing power consumption and radio wave interference. In this paper, we consider only downstream transmission from the gateway node to relay nodes.

B. Radio wave interference model

Here, we explain the model of radio wave interference between links. Figure 3 shows the situation where link $l_{i,j}$ between nodes v_i and v_j interferes with link $l_{p,q}$ between nodes v_p and v_q. Here, v_i and v_p are sender nodes, and v_j and v_q are receiver nodes. The transmission range of v_i is t_i. We define the interference ratio as γ, and thus the interference range r_i of v_i is represented as $\gamma \cdot t_i$.

In Figure 3, v_q is located within the interference range r_i of v_i, which is expressed with parameters as $||v_i - v_q|| < r_i$ ($||v_i - v_j||$ means the physical distance between v_i and v_j). When $l_{i,j}$ and $l_{p,q}$ transmit data at the same time, v_q cannot correctly receive the signal from v_p since v_q receives radio waves from both v_i and v_p simultaneously. In this case, $l_{i,j}$ interferes with $l_{p,q}$. Additionally, we define the interference relationship between $l_{i,j}$ and $l_{p,q}$ as the situation where either $l_{i,j}$ interferes with $l_{p,q}$ or $l_{p,q}$ interferes with $l_{i,j}$. These two conditions are represented as $||v_i - v_q|| < r_i$ and $||v_p - v_p|| < r_p$. In other words, when $||v_i - v_q|| < r_i$ or $||v_p - v_p|| < r_p$ is satisfied, the radio wave interference occurs between $l_{i,j}$ and $l_{p,q}$.

C. Time slot assignment algorithm

IEEE 802.16j relay networks resolve the radio interference problem by employing the TDMA scheme. In such networks, time slots are assigned to links as transmission opportunities. For high network performance, it is important to assign different time slots to links that interfere with each other, and to assign the same time slots to links that do not interfere with each other. In this paper, we utilize the scheduling algorithm proposed in [10]. The algorithm assigns time slots to links in the network in accordance with their traffic demands by treating the time slot assignment problem as a vertex coloring problem [11].

III. Node Repositioning Method

In this section, we explain the method to reposition relay nodes under movement range constraints. We assume that the initial positions of relay nodes are determined beforehand, and that we can move certain relay nodes to improve network performance. We take the movement of a node to be constrained within a certain range centered on the node's initial position. In what follows, we first explain the algorithm to determine the repositioning of one node. We then describe how to reposition multiple nodes to further improve network performance.

A. One-node repositioning

In repositioning one node, the selection of the node to be repositioned is important. The target node is determined as follows. We first select a candidate node to be repositioned and find its position that gives the best network performance from all the possible positions. We repeat this process for all

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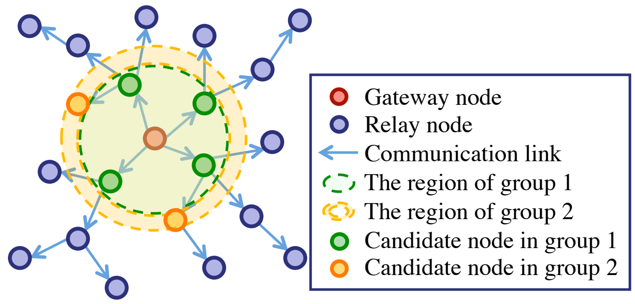

Figure 4. Groups of node repositioning

candidate nodes and find the node and its movement which lead to the best network performance.

However, the computational cost is too large to check all nodes as candidate nodes. Here, we propose limiting the number of candidate nodes according to their distance from the gateway node, as shown in Figure 4. We categorize the candidate nodes as follows. First, nodes that are directly connected to the gateway node are categorized as group 1. Then, the nodes that are not directly connected to the gateway node, but that can be connected to the gateway node by repositioning, are categorized as group 2.

By setting this constraint on the nodes to be checked, we can substantially decrease the computational cost, especially when the number of relay nodes in the network is large.

B. *Repositioning of multiple nodes*

When we reposition multiple nodes to further improve the network performance, we can consider two approaches: parallel repositioning and serial repositioning.

In parallel repositioning, we consider all the possible positions of multiple nodes. Doing so gives the optimal solution for the repositioning of multiple nodes but at a high computational cost that increases greatly with the number of repositioned nodes.

On the other hand, in serial repositioning, we sequentially apply the one-node repositioning method described in Section III-A. This strategy can be regarded as a simple hill-climbing heuristic[12]. Therefore, the computational cost is lower in comparison with parallel repositioning, but the global optimal solution might not be found.

In Section IV, we compare the serial and parallel methods and show that serial repositioning is effective in terms of both computational cost and network performance.

IV. PERFORMANCE EVALUATION

In this section, we evaluate the performance of the node repositioning method proposed in Section III through simulation experiments.

A. *Simulation settings and performance metrics*

We perform simulation experiments under the following conditions. A gateway node is deployed at the center of a 1×1 field, and 9, 29 or 49 relay nodes are randomly deployed. We refer to these three setups as the 10-node network, 30-node network, and 50-node network, respectively. The maximum transmission range of the gateway node and the relay nodes are set to 0.56 for the 10-node network, 0.32 for the 30-node network, and 0.25 for the 50-node network, so that no relay node is disconnected from the network in the initial setup. The radio interference ratio γ is set to 2.

The movement range is set to 1/10 of the maximum transmission range. When moving one node, we consider three methods for establishing the candidate positions as shown in Figure 5. These three methods differ in the resolution of the positions. We can expect that a finer resolution will give better network performance but at a higher computational cost.

The traffic demand from each node depends on the size of the Voronoi diagram [13] of the node. The number of time slots necessary for each link is determined according to the traffic demands. Time slots are assigned to the links by the algorithm proposed in [10]. The number of time slots assigned to all links in the network is called the frame length. The frame length is an important metric of network performance, and a smaller value corresponds to higher network performance.

The change in network performance from repositioning is evaluated in terms of frame length ratio, which is the ratio of the frame length of the repositioned network divided by that of the original network. We conducted 100 simulation experiments for each parameter setting and evaluate the distribution of the frame length ratio. We also measured the time required to perform the calculation in order to evaluate the computational cost.

B. *Effect of movement resolution*

We first evaluate the effect of movement resolution (Figure 5) on the performance of one-node repositioning. Here, we move only one node in a 10-node network.

Figure 6 shows the distribution of frame length ratio for 100 simulation experiments. Nearly the same result was obtained for all movement resolutions. This means that the coarsest resolution is adequate when calculating one-node movement. Therefore, we use the coarsest resolution in the following experiments.

C. *Performance of one-node repositioning*

We evaluated the performance of one-node repositioning in more detail. Specifically, we investigated the effect of limiting the number of candidate nodes, as shown in Figure 4. The frame length ratios obtained using the proposed method with only group 1, only group 2, and both groups 1 and 2 are compared with the ratio obtained using the method where

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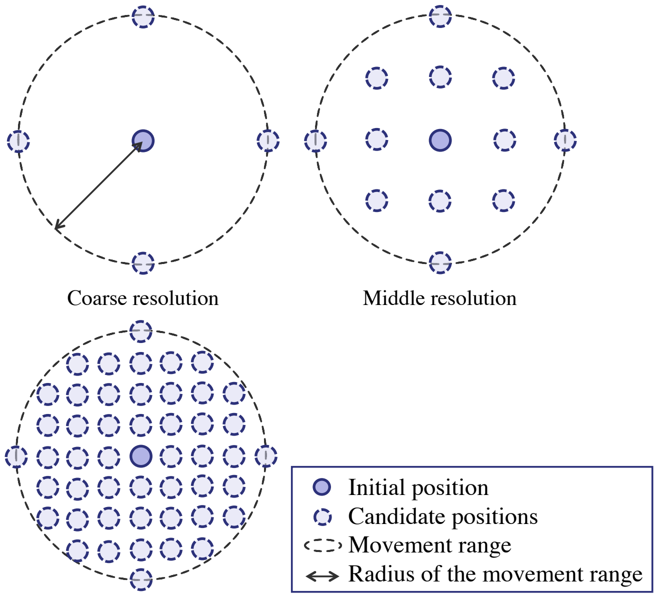


Figure 5. Resolution of movement positions

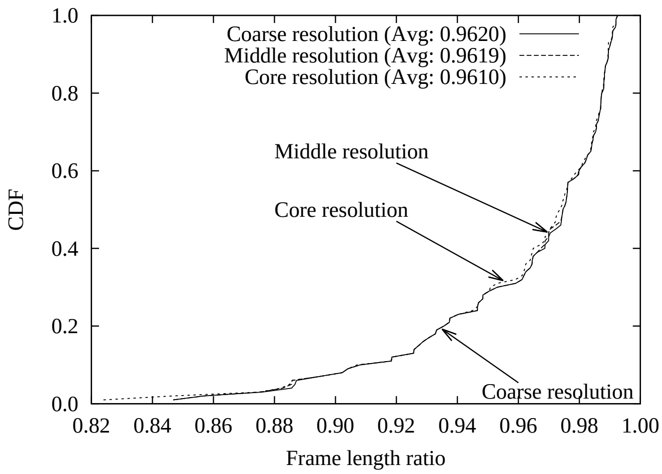


Figure 6. Effect of movement resolution

every node is checked. Note that checking all nodes gives the global optimal solution for one-node repositioning.

Figure 7 shows the distributions of frame length ratio from 100 simulation experiments for the 10-node network, 30-node network, and 50-node network. The result of one-node repositioning using only group 1 or 2 is far from optimal, but repositioning with both groups 1 and 2 is nearly optimal. Furthermore, the result remains unchanged, 5–7% average improvement in the frame length ratio, regardless of the number of relay nodes in the network.

These results indicate that compared with the exhaustive search method, the proposed one-node repositioning method can decrease the frame length substantially at a lower computational cost.

D. Multiple node repositioning

We next evaluate the performance of multiple node repositioning. In detail, we compare the performance of parallel repositioning with all nodes being candidate nodes (giving optimal results), and the serial repositioning with candidate nodes limited to groups 1 and 2. By using the 30-node network, we move 2–3 nodes in the parallel method and 2–9 nodes in the serial method. Note that we cannot execute the simulation experiment of the parallel method using more than 4 repositioned nodes since the calculation time is too large.

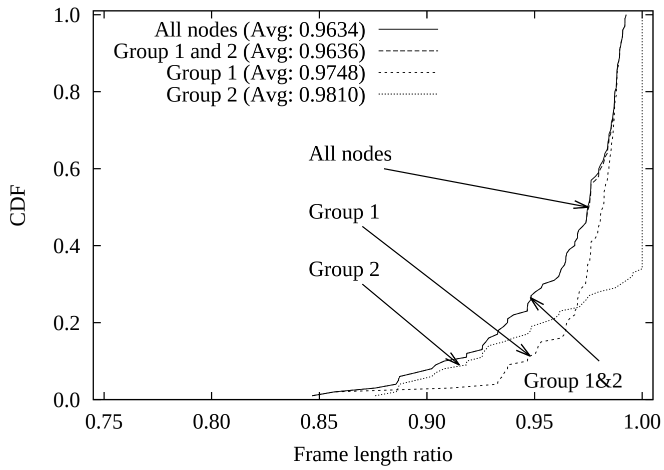
Figure 8 shows the distributions of frame length ratio from 100 simulation experiments with 2–3 nodes being repositioned. We can observe from this figure that as the number of repositioned nodes increased, the results from the serial repositioning method with both groups 1 and 2 became slightly worse than the optimal results. However, considerably better results were obtained from serially positioning using both groups 1 and 2 than from serial repositioning with group 1 or group 2 alone. These results show that limiting the candidate nodes to both groups 1 and 2 is still effective, even in multiple node repositioning.

Furthermore, serial repositioning has a large advantage in terms of computational cost. In Figure 9, we plot the calculation times of the parallel and serial repositioning methods, which were executed on a PC with four 2.93 GHz quad-core CPUs and 64 GB of memory. This figure clearly shows the small computational cost of the serial repositioning method.

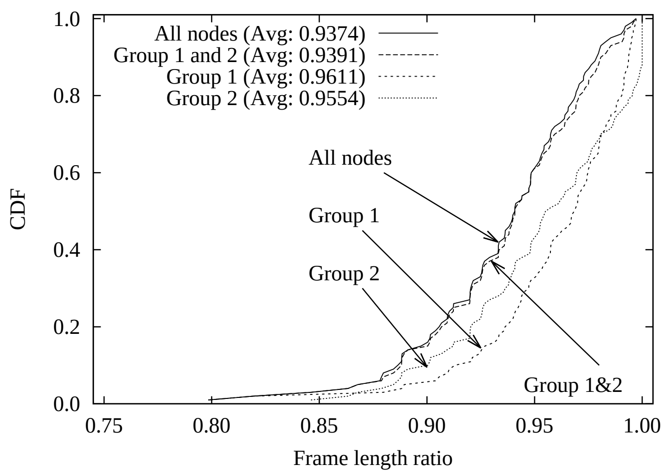
Figure 10 shows the distribution of frame length ratio from 100 simulation experiments using the serial repositioning method with 1–9 nodes being repositioned in the 30-node network. The results show little change for more than 5 nodes being repositioned. In addition, by using the serial repositioning method with 9 nodes, the frame length ratio was improved by up to 28% and 10% on average, which is almost the same as the result of the parallel repositioning method with 3 nodes (Figure 11), while the calculation time is quite small as shown in Figure 9. We can conclude from these results that, by the proposed method, serial repositioning with a portion of the nodes is sufficient for realizing a notable performance improvement.

V. Conclusions and future work

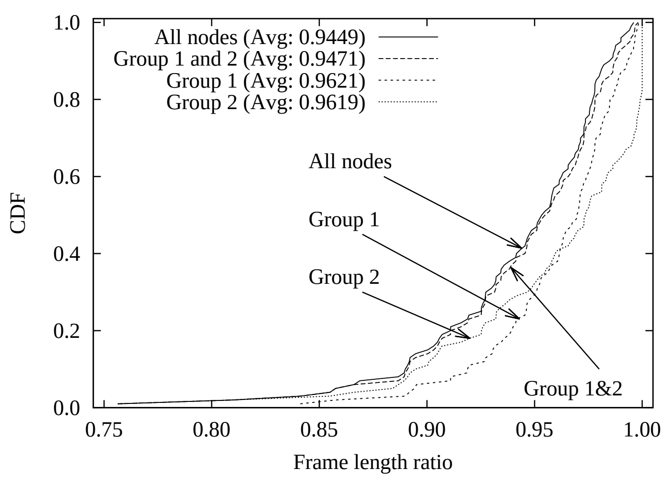
In this paper, we proposed a node repositioning method to improve the performance of IEEE 802.16j relay networks. A low computational cost in multiple node repositioning was realized by limiting the number of candidate nodes and by repositioning multiple nodes in series. The proposed method achieves sufficient effectiveness by repositioning a small number of relay nodes and brings about a nearly optimal



(a) 10-node network

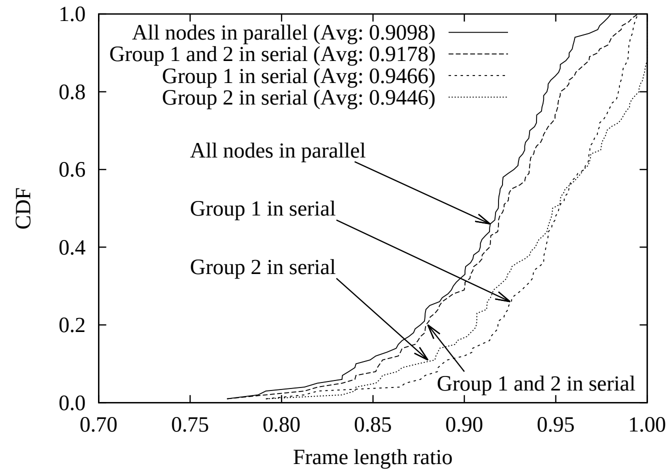


(b) 30-node network

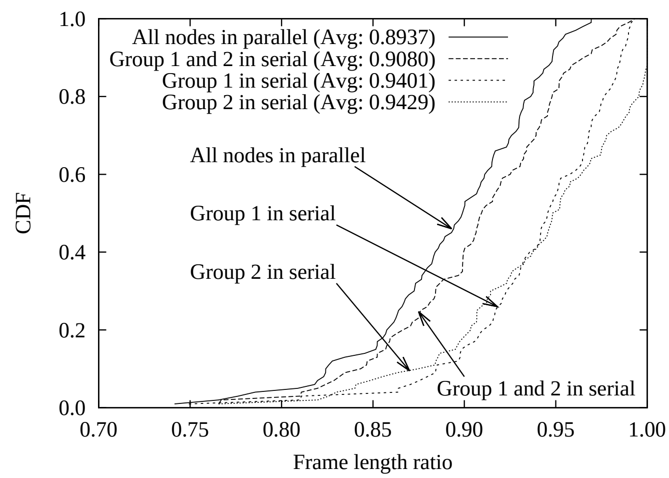


(c) 50-node network

Figure 7. Performance of one-node repositioning



(a) 2 nodes repositioning



(b) 3 nodes repositioning

Figure 8. Frame length ratio from multiple node repositioning

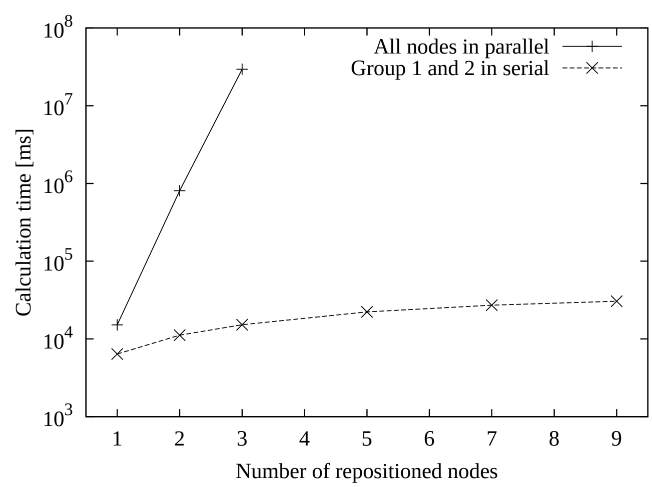


Figure 9. Calculation time for multiple node repositioning

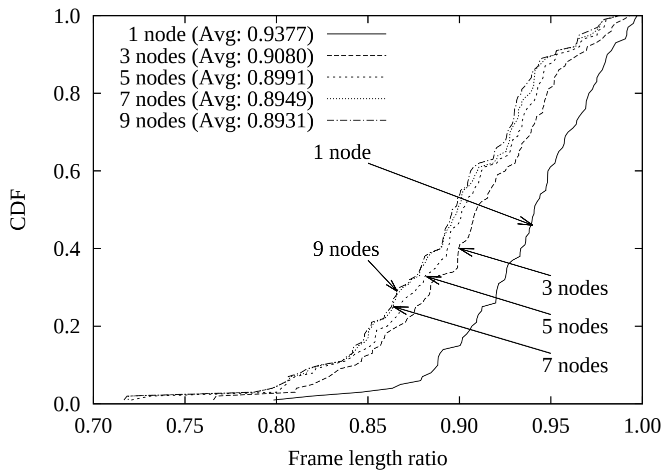


Figure 10. Frame length ratio from multiple node repositioning using both groups 1 and 2

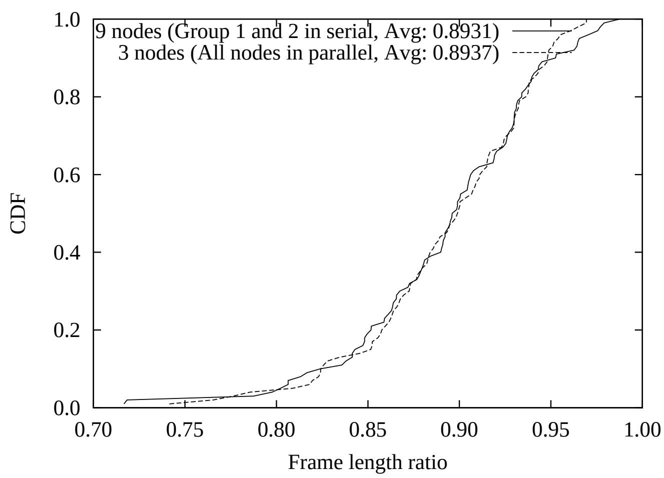


Figure 11. Comparison of multiple node repositioning

performance improvement, but at much lower computational cost than an exhaustive search.

In future work, we will consider ways to further improve the serial repositioning method. We will also evaluate the effects on upstream link and the effectiveness of the proposed method with more accurate radio interference models such as the signal-to-interference noise ratio model [14].

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