Service area deployment of IEEE 802.16j wireless relay networks: service area coverage, energy consumption, and resource utilization efficiency

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***Abstract*—In wireless relay networks based on IEEE 802.16j, each relay node has its own service area that provides wireless Internet access service to the client terminal. The performance of such networks is heavily affected by how each relay node determines its service area size. In order to determine the service area size for each relay node, it is important to use the location information of other neighboring nodes and their service area sizes. However, in general, such information is completely unknown or only partially known. In the present paper, we introduce three methods to determine the service area size, each of which assumes a different level of the knowledge regarding neighboring nodes. We conduct extensive simulation experiments to evaluate the performance of these three methods in terms of coverage ratio, service area overlap characteristics, energy consumption, and utilization efficiency of wireless network resources. We confirm the trade-off relationships between the knowledge level and performance for these three methods.**

***Keywords*-WiMAX; IEEE 802.16j; relay networks; service area; energy consumption;**

I. INTRODUCTION

IEEE 802.16j relay networks [2] (hereinafter referred to as relay networks), which are often referred to as wireless mesh networks, have received significant attention as extensible, cost-effective means to provide a wide-area wireless broadband access environment. In relay networks, each relay node connects to other relay nodes through wireless links so that the overall topology becomes a tree-like structure, as shown in Figure 1. Each relay node is connected to the Internet through a gateway node that has a wired connection to the Internet. The relay node provides wireless Internet access service to client terminals within its service area. Generally, the wireless channel used for communication between relay nodes and client terminals is different from that used among relay nodes. Communication quality for client terminals is heavily affected by the service area construction. In an area where multiple service areas overlap, the communication quality for the client terminals degrades due to radio interference. IEEE 802.16 uses the TDMA-based transmission mechanism, which assigns time slots to each communication link between relay nodes and client terminals. This means that the links in the overlap area would be assigned different time slots in order to avoid transmission collapse. Therefore, when the overlap area size becomes large or the number of overlapping areas increases, the total number of time slots required for all communication links increases, which decreases the network throughput. Furthermore, since IEEE 802.16 uses the contention-based mechanism for client terminals to join the network [3, 4], service area overlaps would increase access collisions.

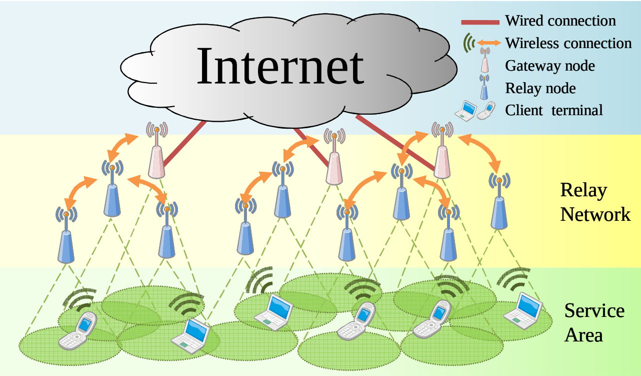

Figure 1: Wireless relay network and client terminals

On the other hand, we should increase the total coverage ratio to provide wide-area and uniform service to client terminals. One possible way to do this is to increase the service area size for each relay node, but this increases the service area overlaps. Furthermore, this also increases the energy consumption of the relay nodes. In other words, there are complex trade-off relationships among network performance, energy consumption, coverage ratio, and service area overlaps.

In order to determine the service area size for each relay node, the information on the location of other neighboring nodes is quite important. However, such information is un-

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[1] The present manuscript is an extended version of [1], which was presented at UBICOMM 2009, October 2009.

known, especially when considering the random installation of relay nodes. In other cases, such information is partially known through the topology construction procedure. In the extreme case, we can obtain precise location information of relay nodes when we install the nodes in a well-organized manner. Therefore, various methods are needed to determine the service area size according to the knowledge level of the location information of neighboring relay nodes.

In [1], we proposed two methods, and compared their communication performance in terms of the size of the total service area, the size of the single-covered area, and the maximum number of overlapped service areas through preliminary simulation experiments. We assume that the service area is a circle. These methods determine the radius of this circle (hereinafter referred to as the service radius). The first method, referred to as the identical radius method, is for the situations, in which there is no information about other relay nodes. Therefore, all of the relay nodes use an identical service radius. The second method, referred to as the NND (Nearest Neighbor Distance) method, is used in situations, in which some degree of topology information can be obtained from the topology construction procedure. Using this information, each node estimates the distance to the nearest neighboring node and sets the service radius.

In this paper, we propose the third method. The third method, referred to as the Voronoi method, is used in situations, in which we can obtain precise location information of other neighboring relay nodes. In this method, each relay node sets its service radius to the distance from the relay node to the furthest point in its Voronoi area [5].

These three methods assume a different level of knowledge. The goal for the future is to develop a method whose performance is highly competitive with Voronoi method, using limited information such as topology construction information. For this purpose, in this paper, we conduct extensive simulation experiments to evaluate the performance of three methods in terms of coverage ratio, service area overlap characteristics, energy consumption, and the utilization efficiency of wireless network resources. We confirm the trade-off relationships between the knowledge level and the performance of the three methods. The simulation results reveal that the method that uses more information performs better in terms of all of the above metrics. In particular, the Voronoi method has the best performance among the three methods, whereas the location information cannot be easily obtained. We also confirm that the performance of the NND method is significantly improved by the inclusion of a small amount of additional information, which is readily available.

The remainder of the present paper is organized as follows. In Section II, we discuss research related to the coverage problem. In Section III, we describe the model of the relay networks and the topology construction method. In Section IV, we introduce three methods to determine the service area size. We present the simulation results in Section V. Finally, in Section VI, we conclude the paper and describe areas for future research.

II. RELATED WORK

As mentioned in Section I, a relay node must determine its service radius so that overlapping areas becomes small and the total service area becomes large. This problem can be classified as a disc coverage problem, which has been researched extensively with respect to sensor networks [6, 7], relay networks [8], and image processing [9]. However, these studies cannot be applied to the problem in the present paper because the assumptions are quite different. For example, in [6, 7], individual sensors cannot change their coverage ranges. In [9], the authors discussed a method to choose a set of discs from various size discs so that the total area is covered by the smallest possible number of discs and the size of discs is fixed. In [8], the authors focused on the coverage problem in relay networks and investigated the adequate number of relay nodes for client terminals to establish a path to the gateway nodes. They also investigated the process of changing the coverage ratio, which is the ratio of the number of client terminals with an active link to the total number of client terminals. However, the previous authors assumed that they could install additional relay nodes so that the client terminals could establish a path to the gateway node.

III. IEEE 802.16J RELAY NETWORK

In this section, we describe the network model and the radio interference model used in the present paper. We also introduce the topology construction method.

A. Network model

Figure 2 shows the network model used in the present paper. In the network model G, we assume that a set of relay nodes $V = \{v^{(0)}, v^{(1)}, ..., v^{(N-1)}\}$ and a set of client terminals $W = \{w^{(0)}, w^{(1)}, ..., w^{(Q-1)}\}$ are randomly located in the field and that the relay node at the center of the field is the gateway node $(v^{(0)})$.

The relay nodes and client terminals construct a tree topology based on the topology construction procedure described in Subsection III-C. In topology construction, each relay node $v^{(i)}$ sets its transmission power in a non-stepwise manner. Let $d^{(i)}$ denote the transmission distance of each relay node. Here, $M^{(i)}$ represents the number of physical links of node $v^{(i)}$ that connect to neighboring relay nodes. Note that a physical link is defined as a link that is established between two relay nodes located within each other's transmission distance, and an active link is defined as a physical link that constructs a tree topology and is used to transmit data to the gateway node.

We consider two types of wireless communications: wireless communications among relay nodes and wireless communications between relay nodes and client terminals. These two types of communications do not interfere with each

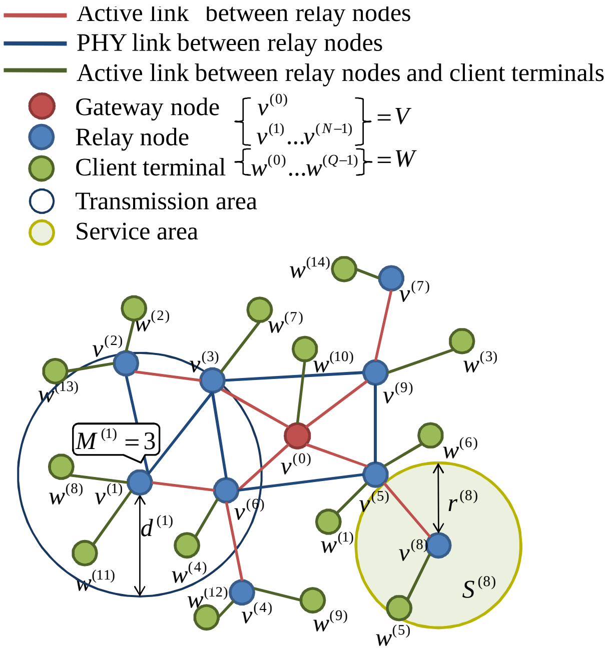


Figure 2: Network model

other because they use different wireless channels [10]. We assume that the service area of relay node $v^{(i)}$ is a circle $S^{(i)}$, the radius of which is $r^{(i)}$, and the service radius can be chosen in a non-stepwise manner. We also assume that client terminals always set a constant transmission distance regardless of the distance to the connecting relay node. After the topology construction introduced in Subsection III-C, each relay node determines its service area size in order to provide wireless Internet access service for client terminals. Each client terminal connects to the nearest relay node having a service radius area that covers the client terminal.

B. Directed interference model

We next introduce the radio interference model [11] used in the present paper, as is depicted in Figure 3. We define a directed communication graph $I = (X, E)$, where $X = V \cup W$ and E is the set of directed communication links $l_{v^{(i)},w^{(p)}}$ that defines an edge directed from relay node $v^{(i)}$ to client terminal $w^{(p)}$. Note that the communication links between relay nodes are not included in E. The model defines the interference relationship between two directed transmission links $l_{v^{(i)},w^{(p)}}$ and $l_{v^{(j)},w^{(q)}}$ based on the distance among four vertices $v^{(i)}$, $v^{(j)}$, $w^{(p)}$, and $w^{(q)}$. In the communication between relay nodes and client terminals, we assume that $v^{(i)}$ and $w^{(p)}$ have interference ranges given by circles of radii are $u_v^{(i)}$ and $u_w^{(p)}$, respectively. In IEEE 802.16j, upward links and downward links become active in different sub-frames. Therefore, we have to consider the following two types of interferences. For upward interference, $l_{v^{(j)},w^{(q)}}$ interferes with $l_{v^{(i)},w^{(p)}}$ when and only when $||v^{(i)} - w^{(q)}|| < u_w^{(q)}$. For downward interference, $l_{v^{(i)},w^{(p)}}$ interferes with $l_{v^{(j)},w^{(q)}}$ when and only when $||v^{(i)} - w^{(q)}|| < u_v^{(i)}$. Here, $||v^{(i)} - w^{(q)}||$ is the distance between $v^{(i)}$ and $w^{(q)}$. Typically, $u^{(i)} > d^{(i)}$, and the ratio of the interference range to the communication range for node $v^{(i)}$, denoted as $\gamma^{(i)} = \frac{u^{(i)}}{d^{(i)}}$, takes ranges from 2 to 4 in practice [11]. When the two links interfere, they are not used at the same time slot in the IEEE 802.16 frame.

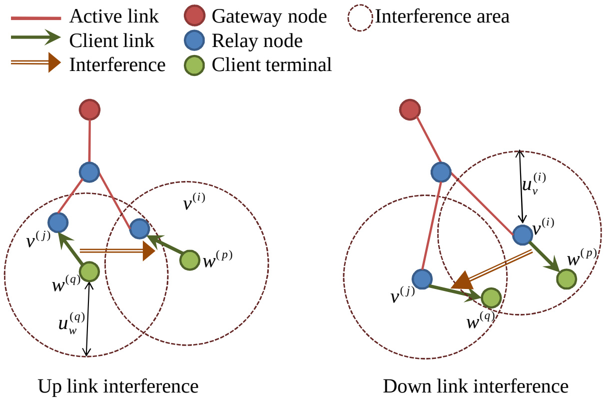


Figure 3: Directed interference model

C. Topology construction procedure

IEEE 802.16j does not define the details of the method used to construct the network topology [12]. The topology construction procedure we introduce here is targeted at situations, in which relay nodes are deployed randomly. The typical situation includes network construction at a disaster site, where it is difficult to deploy relay nodes in a well-organized manner. We also assume that relay nodes are deployed to the network incrementally. In the following, we explain in detail the algorithm for a newly joining relay node to connect to an existing network topology.

A newly joining relay node, denoted as $v^{(i)}$, waits for replies from other existing relay nodes while increasing its radio transmission power [3]. When a found relay node does not have a path to a gateway node, $v^{(i)}$ establishes a physical link to the relay node and continues increasing its transmission power. When the found relay node has a path to the gateway node, $v^{(i)}$ establishes an active link to the relay node and stops increasing its transmission power. When $v^{(i)}$ cannot find any relay nodes even when the transmission power reaches the maximum, $v^{(i)}$ maintains the maximum transmission power to detect the joining relay nodes which is successfully linked to the gateway node. If the relay node finds multiple relay nodes that have a path to the gateway node at the same time, the relay node sets an active link to the relay node that has the smallest hop count to the gateway node. When multiple relay nodes have an identical

Algorithm 1 Algorithm for complete coverage of the field using the identical radius method

```
Input: topology $T_n$
Output: length of service radius $r_{idt}$
Declare variable $tempDist$
Declare variable $coverageRatio$
$tempDist = 0.6$
$coverageRatio = 100\%$
while $coverageRatio = 100\%$ do
    $tempDist = tempDist - 0.005$
    Calculate the $coverageRatio$ using all of the service radii $r^{(i)} = tempDist$
    if $coverageRatio < 100\%$ then
        BREAK
    end if
end while
Return $r_{idt} = tempDist + 0.005$
```

hop count to the gateway node, $v^{(i)}$ chooses the relay node that is nearest $v^{(i)}$. When a relay node $v^{(j)}$ that does not have an active link finds a path to the gateway node as a result of the entry of $v^{(i)}$, $v^{(i)}$ and $v^{(j)}$ set active links as the shortest path to the gateway node.

Note that this topology construction procedure may generate isolated relay nodes, which do not connect any other relay nodes and which cannot provide a service area, depending on its transmission distance, deployment order of relay nodes, and location. The simulation experiments shown in Section V include such a case.

IV. METHODS TO DETERMINE THE SERVICE AREA SIZE

A. Identical radius method

As the simplest method, we first discuss the identical radius method. This method is used in situations, in which there is no information about other relay nodes. In this method, all relay nodes use an identical service radius. This method determines the service radius as the minimum value so that the coverage ratio becomes 100%.

Each relay node determines its service radius $r^{(i)}$ according to the following equation, where r_{idt} is obtained by algorithm 1:

$$r^{(i)} = r_{idt}. \tag{1}$$

Figure 4 shows an example of coverage with the identical radius method.

B. Nearest neighbor distance method

Nearest neighbor distance (NND) method is used in situations, in which some degree of topology information can be obtained by the topology construction. The NND method estimates the nearest neighbor distance, which is the distance to the nearest neighboring relay node, based on the node density, using this information. This estimation result is used to determine the service radius.

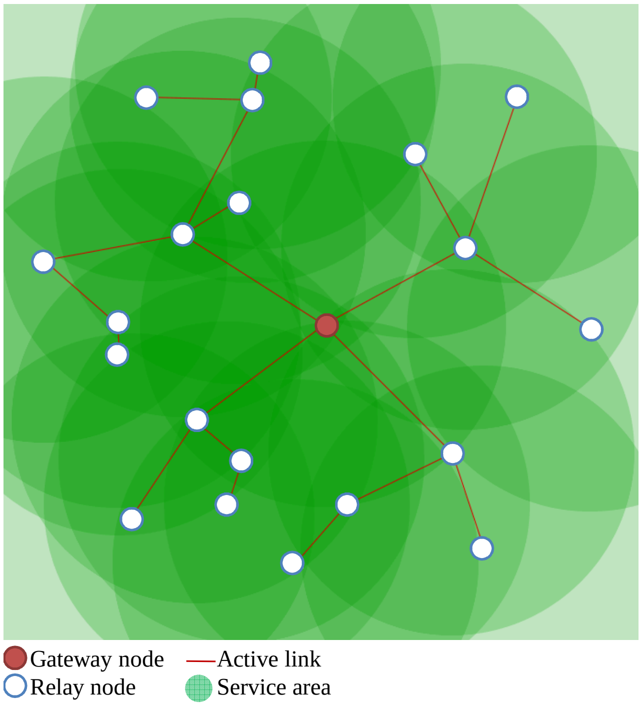


Figure 4: Example of coverage by the identical radius method

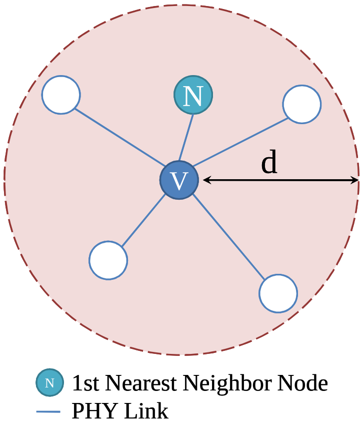


Figure 5: Estimation of the nearest neighbor distance

1) Estimation of the nearest neighbor distance: Figure 5 shows the situation, in which relay node v has M (= five) neighboring nodes in its transmission distance, which means that relay node v has M physical links. Since we assume the random location of all relay nodes, M neighboring relay nodes are randomly located in the circle for which the center is located at node v and the radius is d. We then derive the nearest neighbor distance using parameters M and d.

First, we consider a lemma for the estimation.

Lemma IV-B.1. *When the node density is constant and* *there are M relay nodes in a circle C_α of radius α, the average distance $\overline{R}$ between these nodes and the center node becomes:*

$$\overline{R} = \frac{2\alpha}{3}.$$

Proof: Let $P_{(t|0 \le t \le \alpha)}$ be the node density function on the circumference of a circle of radius t in C_α. Since nodes are randomly located, $P_{(t)}$ is proportional to t. Therefore, with invariable c, $P_{(t)}$ becomes as follows:

$$P_{(t)} = c \cdot t. \tag{2}$$

Here, since the number of relay nodes in C_α is M, we have

$$\int_0^\alpha P(t)dt = M. \tag{3}$$

Using Eq. (2) and (3), c satisfies

$$c = \frac{2M}{\alpha^2}. \tag{4}$$

Substituting Eq. (4) into Eq. (2), we obtain the following:

$$P(t) = \frac{2M}{\alpha^2}t. \tag{5}$$

Therefore, $\overline{R}$ becomes as follows:

$$\begin{aligned} \overline{R} &= \frac{1}{M} \cdot \int_0^\alpha t \cdot P(t)dt \\ &= \frac{2\alpha}{3}. \end{aligned} \tag{6}$$

■

Using lemma IV-B.1, we have the following theorem.

Theorem IV-B.1. *If the number of PHY links M and the transmission distance d of a relay node are known, the average distance to the nearest neighbor node $\overline{R_1}$ becomes as follows:*

$$\overline{R_1} = \frac{2d}{3\sqrt{M}}.$$

Proof: Considering that the fraction between 1 and the number of relay nodes in the circle C_d is equal to the fraction between the area of C_{R_1} and C_d, we have

$$\frac{M}{\pi d^2} = \frac{1}{\pi (R_1)^2}. \tag{7}$$

Thus, R_1 satisfies

$$R_1 = d\sqrt{\frac{1}{M}}. \tag{8}$$

Using lemma IV-B.1, the average distance to the nearest neighbor node $\overline{R_1}$ becomes as follows:

$$\overline{R_1} = \frac{2d}{3\sqrt{M}}. \tag{9}$$

■

2) Accuracy of estimation: We conducted simulations to evaluate the performance of the estimation algorithm. In this simulation, 100 relay nodes are randomly deployed in a 1×1 field according to the joining process described in Subsection III-C. We then obtain the estimated and actual values of the nearest neighbor distance for all relay nodes. The simulation was conducted 100 times for different node locations. Figure 6 show the relation between the actual and estimated values of the nearest neighbor distance. The two straight lines represent the least-squares approximation and the $y = x$ relationship between the actual and estimated values. When the relay node estimates its nearest neighbor distance precisely, the dots in the graph should be plotted on the $y = x$ line. However, as shown in Figure 6, this algorithm has a large estimation error. Moreover, this algorithm overestimates the nearest neighbor distance when it is less than 0.05 and underestimates the nearest neighbor distance when it is larger than 0.05 on average. This error stems from the topology construction procedure. As mentioned in Subsection III-C, a relay node stops increasing its transmission power when the node finds a neighboring node that has a path to the gateway node. This means that, in most cases, some neighboring nodes exist on the circumference of a circle. On the other hand, this algorithm assumes that the neighboring nodes exist randomly in the circle.

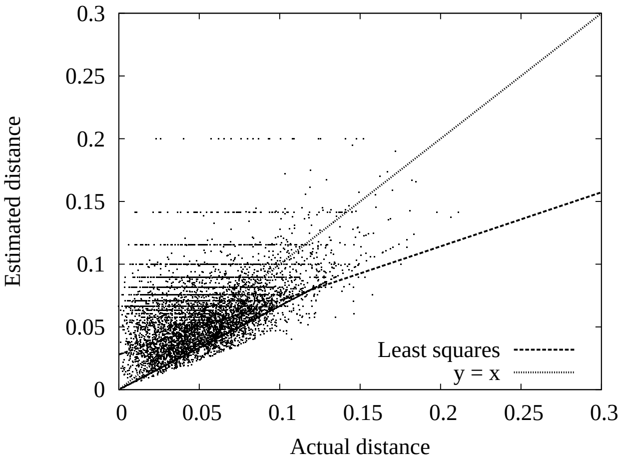


Figure 6: Estimation accuracy

3) Algorithm for complete coverage of the field using the NND method: In the NND method, each relay node sets its service radius based on the estimation result of the nearest neighbor distance (Eq. 9), where d and M can be obtained through the topology construction procedure. Specifically, each relay node determines its service radius $r^{(i)}$ according to the following equation:

$$r^{(i)} = \overline{R_1^{(i)}} \times k_{nnd}, \tag{10}$$

where $\overline{R_1^{(i)}}$ is the nearest neighbor distance of node $v^{(i)}$ defined in Eq. 9 and k_{nnd} is the parameter for determining the overall degree of the service radius (referred to in

Algorithm 2 Algorithm for complete coverage of the field using the NND method

```
Input: Topology $T_n$
Output: Value of service ratio $k_{nnd}$
Declare variable $tempRatio$
Declare variable $coverageRatio$
$tempRatio = 5$
$coverageRatio = 100\%$
while $coverageRatio = 100\%$ do
    $tempRatio = tempRatio - 0.1$
    Calculate the $coverageRatio$ using all of the service radii $r^{(i)} = R_1^{(i)} \times tempRatio$
    if $coverageRatio < 100\%$ then
        BREAK
    end if
end while
Return $k_{nnd} = tempRatio + 0.1$
```

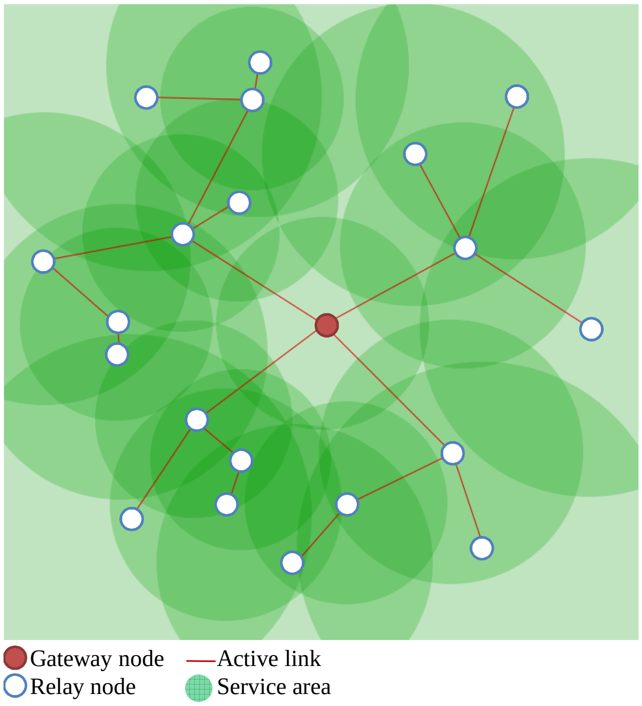


Figure 7: Example of coverage by the NND method

algorithm 2 as the service ratio). Using algorithm 2, we set k_{nnd} so that the coverage ratio becomes 100%. Figure 7 shows an example of coverage with the NND method.

C. *Voronoi method*

As mentioned in Subsection III-C, we assume that each client terminal connects to the nearest neighboring node. This means that each relay node accepts connections from the client terminals in its Voronoi area [5]. Based on this observation, in the Voronoi method, each relay node set its service radius to cover its Voronoi area. Figure 8 shows an image of the coverage obtained by using the Voronoi method. We assume in this method that we can obtain precise location information of all neighboring relay nodes and calculate the Voronoi area. The Voronoi method sets the service distance to the farthest point in the Voronoi area (referred to in Figure 8 as the maximum Voronoi distance). Note that this method can provide 100% of the coverage ratio because the coverage ratio is based on the Voronoi area. Figure 9 shows an example of coverage obtained by using the Voronoi method.

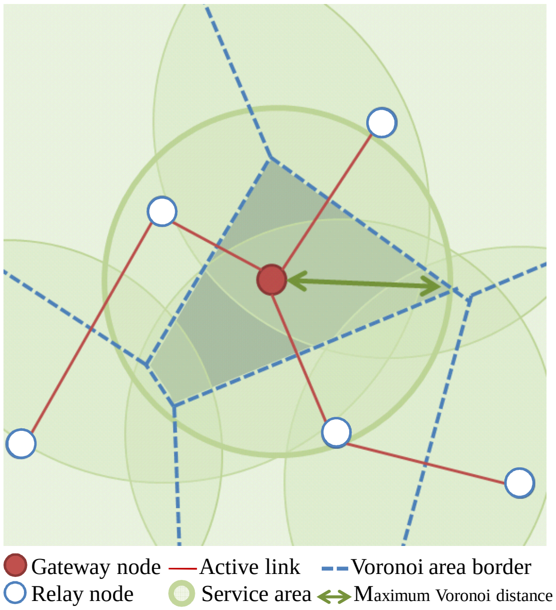


Figure 8: Voronoi method

V. PERFORMANCE EVALUATION

We show the evaluation results for the three methods proposed in Section IV by conducting simulation experiments.

A. *Simulation settings and performance metric*

In the simulation, a gateway node is located at the center of a 1×1 field, and 99 or 49 relay nodes and 500 client terminals are randomly located. As described in Subsection III-C, the relay nodes construct the network topology based on their location and transmission distance and determine the service area size using each method. Each client terminal connects to the nearest neighboring relay node. The maximum transmission distance of relay nodes and client terminals to construct network topology for communication between relay nodes is set to 0.3, and γ is set to 2. Each plot in the following graphs is the average of $1,000$ simulation experiments.

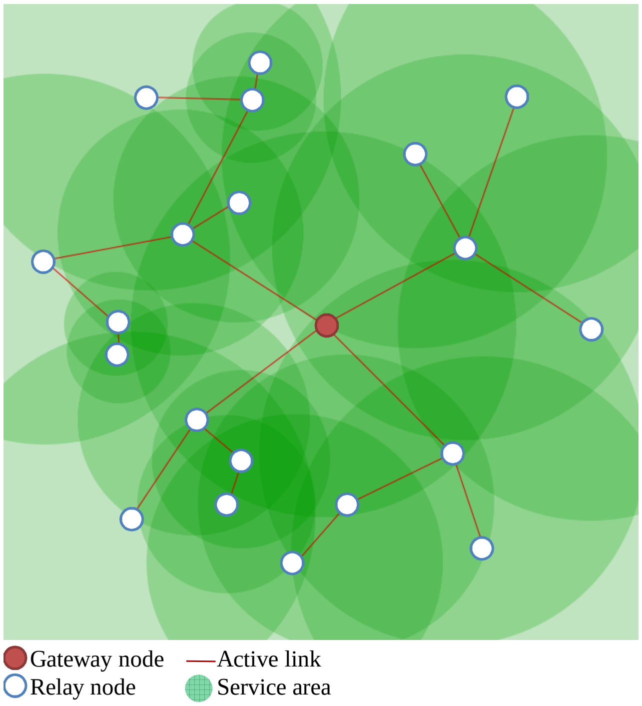


Figure 9: Example of coverage by the Voronoi method

We evaluate the performances of the three methods from following three viewpoints:

- Overlapping service area: We define the *overlap number* of a certain point in the field as the number of relay nodes having a service area that includes the point. We then look at the size distribution of the area in the field summarized by the overlap number. We also use the maximum overlap number, which is defined as the maximum value of the overlap number in the field.
- Energy consumption: We define the energy consumption $E^{(i)}$ of the relay node $v^{(i)}$ as follows [13, 14]:

  $$E^{(i)} = {r^{(i)}}^2. \tag{11}$$

  Then, we calculate the energy consumption of the entire relay network as the sum of the energy consumptions of the relay nodes in the network.
- Wireless resource efficiency: In TDMA-based wireless multi-hop relay networks, in order to prevent radio interference, different time slots are assigned to the links that interfere with each other. The frame length is defined as the sum of the number of time slots that are assigned to all of the network links. When the frame length becomes smaller, we can say that we achieve better efficiency of wireless network resources. Therefore, we adopt the frame length as the metric for wireless resource efficiency. Note that we evaluate the frame length for downlink transmissions since the methods in Section IV affects the performance of downlink communication between gateway nodes and relay nodes. By sharing time slots among multiple wireless links that do not interfere with each other, the frame length can be reduced. Note that the method to determine the frame length is beyond the scope of the present paper. However, in the following, we briefly explain the algorithm presented in [11] used to determine the frame length.
  The problem of finding the time slot assignment to the minimize frame length is known as the NP-hard problem [15]. A heuristic algorithm to obtain the interference-free time slot assignment with a small frame length, based on the greedy algorithm is presented in [11], where this resource allocation problem was considered as a point coloring problem and the number of colors was considered as the frame length. This algorithm is divided into the following two major steps.

  Step 1 Determine the order of links for the coloring based on a conflict graph

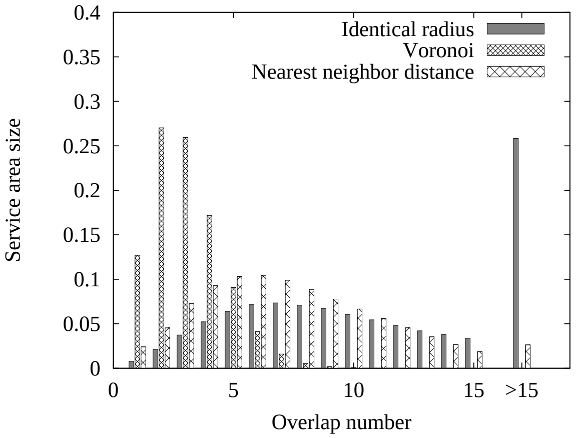
  Step 2 Color each link using the greedy algorithm by the order determined in Step 1

  See [11] for the detailed algorithm. In general, the frame length becomes smaller when the degree of radio interference in the relay network is small. Therefore, the frame length is one possible metric for evaluating service area deployment algorithms.

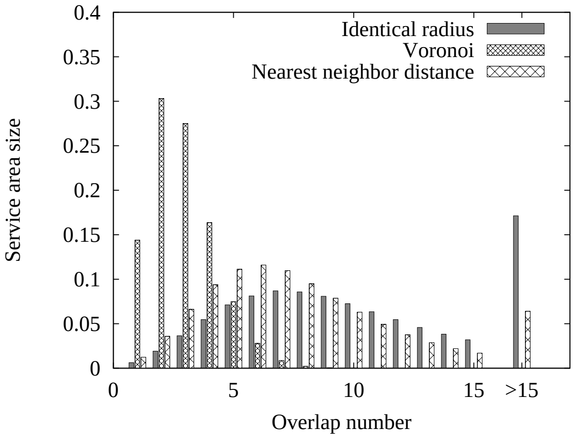
Note that we do not evaluate the coverage ratio because we set the service radius to the minimum value so that the coverage ratio reaches 100%.

B. Overlapping service area

Figures 10(a) and 10(b) show the area size distributions for each overlap number when we use 50 and 100 relay nodes, respectively. In this figure, the area size with an overlap number of 1 represents the single-covered area size, and k of the overlap number indicates that the area is covered by the service areas from k relay nodes. We summarize the area size where the overlap number is larger than 15 at the rightmost bins in the graph. Based on these figures, we observe that when we compare the NND method and identical radius method, the NND method slightly outperforms the identical radius method because the NND method has smaller values of the overlap number than the identical radius method. On the other hand, the results obtained by using the Voronoi method are much better, where roughly 80% of the field has an overlap number of less than five. This indicates the effectiveness of the Voronoi method. Figure 11 shows the CDF of the maximum overlap number for $1,000$ simulation experiments. In Figure 11, we can observe that, as the number of deployed relay nodes increases, the maximum overlap number also increases when we apply the

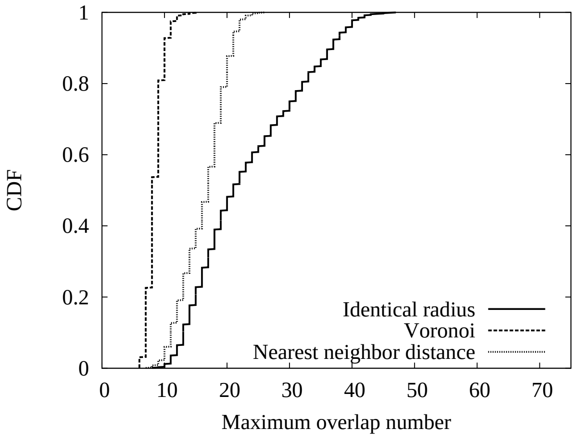


(a) 50 relay nodes

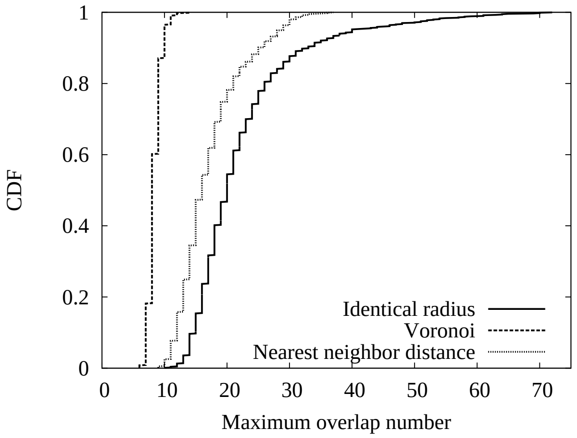


(b) 100 relay nodes

Figure 10: Size distribution of the overlapping area



(a) 50 relay nodes



(b) 100 relay nodes

Figure 11: Distribution of the maximum overlap number

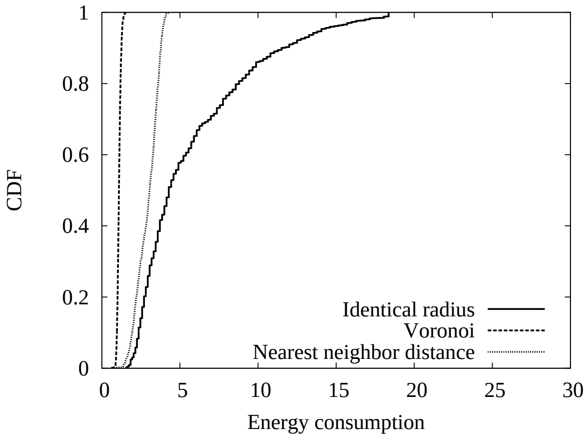
NND method and the identical radius method. On the other hand, when we apply the Voronoi method, the maximum overlap number is not affected by the number of relay nodes.

C. *Energy consumption*

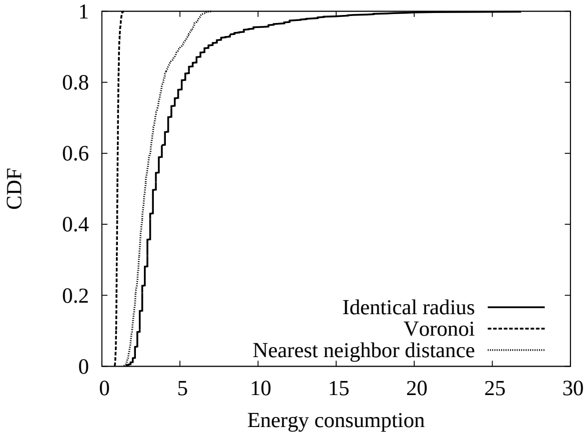
Figure 12 shows the CDFs of the energy consumption of 1,000 simulation experiments for networks with 50 and 100 relay nodes, respectively. Figure 12 resembles Figure 11, which means that the service area coverage efficiency largely affects the energy consumption efficiency. In addition, for the Voronoi method, there is a little difference between the results obtained for 50 relay nodes and the results obtained for 100 relay nodes. This indicates the effectiveness of the Voronoi method, which requires precise location information of all of the relay nodes in the network.

D. *Wireless resource efficiency*

Figure 13 shows the CDF of the frame length of $1,000$ simulation experiments. We can observe that the frame length of the Voronoi method becomes 54% in the case of 50 relay nodes and 59% in the case of 100 relay nodes, as compared to the identical radius method. For the NND method, the frame length in the case of 50 relay nodes is 82% and that in the case of 100 relay nodes is 119%, respectively, as compared to the identical radius method. This means that, in the NND method, the frame length is affected by the node density. However, as shown in Figure 13, the variance of the identical radius method is larger than that of the other methods. This is because the identical radius method cannot accommodate the biased node density.

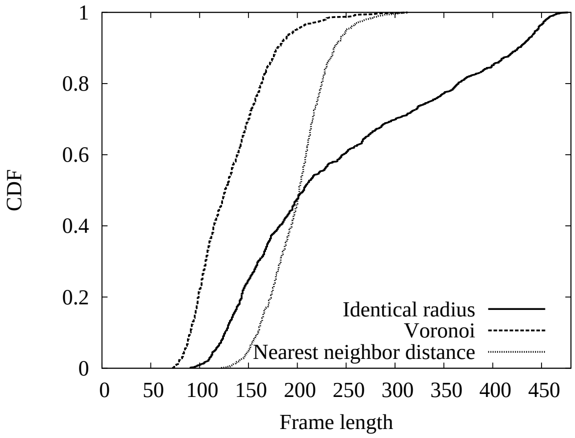


(a) 50 relay nodes

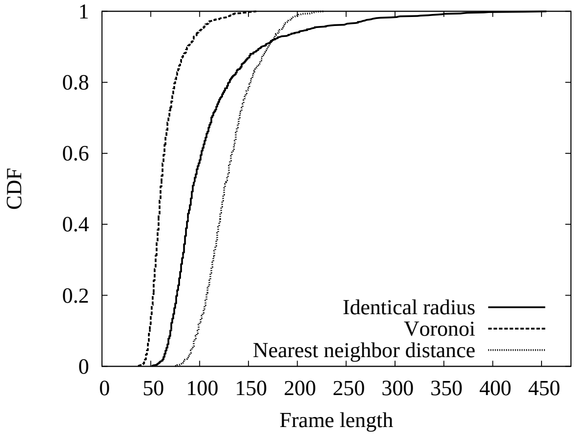


(b) 100 relay nodes

Figure 12: Distribution of network energy consumption



(a) 50 relay nodes



(b) 100 relay nodes

Figure 13: Frame length distribution

Therefore, it is necessary to set a large service radius in order to obtain a coverage ratio of 100%, which causes a large degree of radio interference and a large frame length.

VI. CONCLUSION AND FUTURE WORK

In the present paper, we introduced three methods to determine the service area size for IEEE 802.16j relay nodes, referred to as the identical radius method, the NND method, and the Voronoi method, each of which assumes a different level of knowledge regarding neighboring nodes. The identical radius method is the simplest method, in which all relay nodes use an identical service radius. The NND method is used for situations, in which some degree of topology information of the relay network can be obtained. In this method, each relay node estimates the nearest neighbor distance and sets its service radius based on the estimation results. The Voronoi method is used in situations, in which we can obtain precise location information of other neighboring relay nodes. In this method, each relay node sets its service radius to cover its Voronoi area. Through performance evaluation in terms of service area overlap characteristics, energy consumption, and utilization efficiency of wireless network resources, we confirmed the trade-off relationships between the knowledge level and performances of the three methods considered herein. Specifically, the Voronoi method performs significantly better than the other methods.

In future studies, we intend to develop a method in which each relay node can obtain the shape of its Voronoi area using less information, whose performance is highly competitive with Voronoi method. Furthermore, we intend to evaluate the effect of the service area size on connection establishment procedure based on the contention-based request mechanism.

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