Mesh Router Selection to Maximize System Throughput in Dense Wireless Mesh Networks

Mesh Router Selection to Maximize System Throughput in Dense Wireless Mesh Networks

Panu Avakul*‡, Hiroki Nishiyama*§, Nei Kato*¶, Yoshitaka Shimizu†‖ and Tomoaki Kumagai†**
*Graduate School of Information Sciences, Tohoku University, Sendai, Japan
†NTT Network Innovation Laboratories, NTT Corporation, Yokosuka, Japan
{‡panu0014, §bigtree, ¶kato}@it.ecei.tohoku.ac.jp, {‖shimizu.yoshitaka, **kumagai.tomoaki}@lab.ntt.co.jp

***Abstract*—Wireless Mesh Network (WMN) is a promising networking architecture because of its useful characteristics such as low deployment cost, ease of maintenance, network robustness and reliable coverage. Each node in the network is referred to either as Mesh Router (MR), Mesh Client (MC), or Mesh Gateway (MG) depending on its role in the network. MRs are interconnected to form a mesh backbone network, which can relay communications service from MCs to the MG. In many situations, MRs deployment are uncontrollable, and thus deployed MRs may not have ideal locations. In addition, in a dense network, using all available MRs that are deployed randomly to form mesh backbone network would results in a lower performance than what could be achieved. Therefore, our goal aims to select a set of working MRs that would yield an improved upper bound throughput, while still preserving connectivity. Our contributions include using graphs to represent multi-tier WMN and utilizing them to determine the set of MRs that can be safely removed from the network without severing any connectivity of the network. Furthermore, we proposed algorithm that goes through those set of MRs to determine the MRs which should be removed from the network to improve the overall performance, and we demonstrate capacity improvement brought by our scheme through simulations.**

I. Introduction

Wireless Mesh Network (WMN) is a type of wireless multi-hop network where nodes, known as the Mesh Routers (MR) interconnect with each other to form a mesh network similar to that of the wireless Ad-Hoc network. WMN has many useful characteristics such as low deployment cost, ease of maintenance, network robustness, and reliable coverage [1] which make it useful in many applications. In addition to the radio interface that is dictated to mesh connectivity, MRs are usually equipped with an additional radio interface that is used to provide wireless connectivity to clients, or Mesh Clients (MC) within its area. Some differences between WMN and wireless Ad-Hoc network include the facts that MRs are more likely to be stationary and have no power constraint, whereas Ad-Hocs nodes are usually refer to power limited mobile devices. In addition to mobility and power constraint, there is a slight difference between the Ad-Hoc network and WMN traffic flow. In WMN, traffic tends to flow to/from a certain node which has connectivity to outside network, referred to as Mesh Gateway (MG), whereas each node in Ad-Hoc network usually communicates with one another.

From Fig. 1, it is possible to see that WMN can be partitioned into two different tiers, which include Mesh Tier (MT), and Clients Tier (CT). MT is the interconnection of MG(s) and MRs to form a wireless mesh backbone network, where traffic will be routed to the appropriate MG and to the outside network. In addition to MT, CT is where MG(s) and MRs act as wireless APs in order to provide connectivity to MCs.

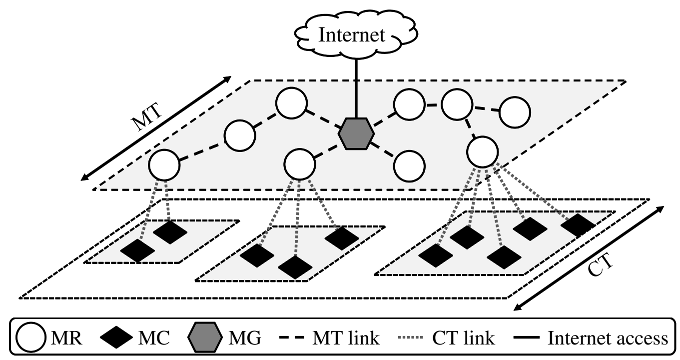


Fig. 1. An example of WMN architecture. MT is composed of interconnection between MRs and MGs, while MR provide communications service to MCs in CT

Communication between MRs in WMN usually shared the same channel with one example such as Roofnet 802.11b WMN deployment from [2]. Therefore, each working router may interfere with another routers and cause the performance of the overall network to be lower than what could be achieved. In addition, it is often not possible to control the deployment factor of WMN due to deployment constraints which worsen the performance even further. Our contributions can be stated as the use of graphs to represents multi-tier WMN and using these graphs to determine the Unnecessary Nodes (UNs), or the set of MRs that can be removed from the network without severing MT or CT connectivity. In addition, we proposed an algorithm that goes through the set of UNs to determine MRs which should be removed from the network in order to improve the overall performance of the network using the concept of Bottleneck Collision Domain (BCD). Finally, we demonstrate through simulations that our algorithm can improve the overall network performance.

The remainder of this paper is organized as follows. Section II discusses the background which includes the introduction of related works and the concept of collision domain. Section III introduces our processes for selecting the number of active MRs and defines necessary information coupled with detailed explanation of our algorithm. Section IV shows and discusses the simulation results. Finally, Section V presents our conclusion.

TABLE I. NOTATIONS USED IN THE PAPER

Notation	Definition/explanation
$l_{\{x,y\}}$, $l_{(x,y)}$	The link between MR_x and MR_y
$P(n)$	Potential traffic of MR_n
$V(l_{(x,y)})$	Value of link $l_{(x,y)}$
CD_{xy}	The CD of link $l_{(x,y)}$
$T(CD_{xy})$	Traffic carried by the CD_{xy}
E_T	Set of ordered pair that represents MT's links of G_T
R_{Tmax}	Maximum transmission distance of MRs in meters
R_{Tn}	Transmission range of MR_n in meters
R_{In}	Interference range of MR_n in meters
N_R	Set of all MRs
N_C	Set of all MCs
E	Set of all edges (unordered pair) of G_V
$d(x,y)$	Distance between MR_x and MR_y
R_{TC}	Maximum transmission range of MCs
E_M	Set of edges (unordered pair) of G_{MV}
$ART(G)$	Set of articulation points of graph G
$C(n)$	Set of clients that are connected to MR_n
$Subtree(y)$	Set of nodes that belong subtree of G_T rooted at y
E_{TC}	Set of ordered pair that represents CT's links of G_T
n_{GW}	Mesh gateway
l_{max}	The link from E_T that has to carry the most traffic
$G'_{T,n}$	Temporary G_T computed from G'_V and G'_{MV} without MR_n

II. BACKGROUND

A. Related Works

It is commonly known that WMN is best deployed by performing a site survey to determine the most ideal locations to place each MR with minimum MR interference and dead spot. However, site surveying is expensive [1] and may take a long time due to the need of sending personnels to the area. [3] presents a method to automatically optimize wireless APs location which can minimize interference from given parameters such as required received power, carrier to interference ratio, and APs' densities. [4] also discuss method for planning wireless APs to maximize overall coverage and signal quality. The pruning algorithm is also discussed, which start with a set of n possible APs, then finds the best APs to be removed. This process is similar to our approach. However, the APs planning approaches mentioned do not deal with the wireless multi-hop nature of WMN, where the APs are interconnected via wireless links. Aside from the works mentioned, there are also other works such as [5] and [6] which proposed APs planning for multi-hop wireless network such as WMN. In [5], the author proposed a method that was able to plan network parameters such as required tower heights, antenna types, and transmission power in order to minimize the cost of deploying the network. In addition, [6] proposed another planning method to minimize the installation cost while still being able to provide full coverage to MCs. These previous works mainly aim to minimize the installation cost, while our objective is to select a set of active MRs from an already deployed set of APs to increase the overall network performance.

B. Upper Bound Throughput

1) Collision Domain: Collision Domain (CD), introduced by [7], is a useful concept that can model interference and estimate upper bound capacity of wireless network. CD uses a common fact that there can only be one single link active within a certain area in order to have a successful transmission.

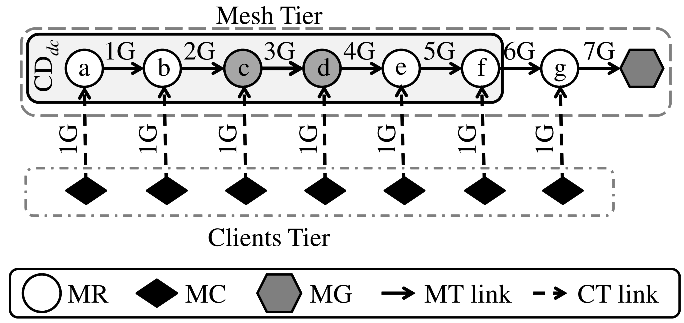


Fig. 2. Chain of line topology that illustrate collision domain of link $l_{(d,c)}$.

We will refer to the link between two MRs, MR_x and MR_y as an unordered pair $l_{\{x,y\}}$ or an ordered pair $l_{(x,y)}$, where MR_x is the parent of MR_y. CD of $l_{\{n,m\}}$ is defined by [7] to be a set of all links that have to be inactive for the duration of the transmission at $l_{\{n,m\}}$ in order to have a successful transmission including the link $l_{\{n,m\}}$ itself. The concept of CD is illustrated in Fig. 2. This figures shows a line topology of an WMN, where each MR is trying to send traffic received from their CT to the sink node or MG on the farthest right in a multi-hop fashion. Each MR or MG can only communicate with MR or MG adjacent to it. In this case, MR_a has to send 1G worth of traffic from its own CT. On the other hand MR_b not only has to send 1G of traffic from its CT but also has to forward those traffic received from MR_a. Therefore, in total, it has to forward 2G worth of traffic. In other words, the downstream MRs have to send both its own CT traffic along with forwarding any traffic from any upstream MRs. We will be referring to the traffic that MR_n has to send from its CT as potential traffic of MR_n, or $P(n)$. Furthermore, the traffic that has to be carried in $l_{(x,y)}$ will be referred to as the value of $l_{(x,y)}$ denoted as $V(l_{(x,y)})$. If it is assumed that interfering range is two hops, it is possible to see from Fig. 2 that the CD of $l_{(d,c)}$, which we will denote as CD_{dc} is the set $\{l_{(b,a)}, l_{(c,b)}, l_{(d,c)}, l_{(e,d)}, l_{(f,e)}\}$. These are the links (excluding $l_{(d,c)}$) that need to be inactive in order to have a successful transmission at $l_{(d,c)}$. We denote the traffic carried by CD_{dc} by $T(CD_{dc})$, which is the sum of the traffic carried by each link of the CD or formally defined as

$$T(\mathrm{CD}_{xy}) = \sum_{l_{(m,n)} \in \mathrm{CD}_{xy}} V(l_{(m,n)}).$$

Another important concept is the Bottleneck Collision Domain (BCD), which is also defined by [7] to be the CD that contains the most traffic. Within the set of routing path links, E_T, the link that has the most traffic, l_{max} is formally defined as

$$l_{max} = \arg\max_{l_{(x,y)}} (T(CD(l_{(x,y)}))) \quad l_{(x,y)} \in E_T, \quad (1)$$

From Eq. (1), we can easily see that BCD of the network is

$$BCD = CD(l_{max}). \quad (2)$$

The BCD of the network in Fig. 2 is the CD_{fe}, because it carries 25G worth of traffic which is the most out of all the links.

2) Theoretical Maximum Throughput: TMT is the theoretical maximum throughput of the MAC layer introduced by [8] as the upper limit throughput that can be achieved with IEEE

802.11 network. This can be calculated using equation from [8] as

$$TMT(x) = \frac{8x}{ax+b} \times 10^6 \text{ bps}, \quad (3)$$

where a and b are constants, which depend on different MAC schemes and spread spectrum technologies. The values of a and b can be found in [8], while x is the MAC Service Data Unit (MSDU) size in bytes.

3) Upper Bound Throughput: The traffic of BCD, or $T(BCD)$ and TMT can be used to calculate the maximum throughput that each MR can achieve in order for the overall network to have no congestion by using the following equation

$$C = \frac{TMT}{T(BCD)} \ . \quad (4)$$

BCD is suitable for estimating capacity of WMN, because it takes into account the routing characteristic of WMN where traffic tends to only flow to/from the MG. Whereas method such as [9] considered the scenario where nodes communicate with one another.

III. SELECTING ACTIVE MRS

A. Motivations and Challenges

Many different deployment factors of WMN are studied in [10], which mention that random deployment is not appropriate due to the low coverage and capacity. However, it is often not possible to deploy MR at their ideal locations. Such scenario includes situations where MRs can be purchased or given to users whom will attempt to set up their MR in an uncontrolled fashion. One example of such situation includes network infrastructure introduced in [11] where MRs are normal wireless APs which are only configure into MR incase of emergency. Another situation is the roofnet deployment introduced by [2], where each MR is set up by volunteer user. Therefore, it is not possible to control the deployment of MR in many practical scenarios. As our previous work suggested, using all available MRs to form a mesh backbone network may result in a lower performance than just using a certain subset of the available MRs [12]. Thus, we aim to improve the performance of randomly deployed WMN by selecting the set of active MRs which would results in the upper bound per client capacity improvement.

One of the main challenges in selecting a set of working MRs is to be able to preserve the connectivity of the network. Since our set of selected MRs is the proper subset of the set of available MRs, the network may become disconnected if unsuitable set are selected. Preserving the connectivity of the network is critical, because we want to be able to provide service to all MCs within the network. Our scheme can ensure that the connectivity of the network is preserved by using the articulation point concept of graph theory to find the MRs that can be removed from the network without disconnecting any MRs or MCs. The concept of articulation point has been used by [13] to monitor wireless sensor network (WSN) connectivity. However, this idea is not applicable with WMN, because WSN is a flat network that contains mostly only a single type of nodes that are capable of similar roles. However, WMN has node diversity such as that different type of nodes are only capable of a certain role. For example, MCs cannot relay traffic, but MRs only relay traffic. This make it impossible to model WMN connectivity using the method that was done in [13].

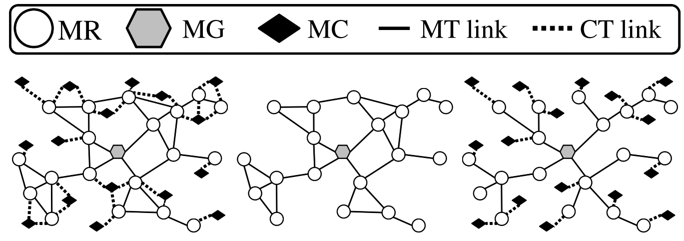


Fig. 3. a) G_V of the given scenario; b) G_{MV} of the given scenario; c) G_T of the given scenario, which represents the routing path

B. Network Model

In this subsection, we introduce our scenario and assumptions. Our scenario is that within a given two dimensional space, a certain number of MRs and MCs are randomly distributed within the given area to represent uncontrolled nodes deployment. All MRs are assumed to have the same maximum transmission range of R_{Tmax}. After the routing path is established, R_{Tn} represents transmission range of MR$_n$ which is the distance between MR$_n$ and its furthest neighbour MR in its routing path. The interfering range of MR$_n$, or R_{In} is twice the R_{Tn}. Even though it is possible to have multiple MGs in the real deployment, we only consider the situation where there is only one MG. This can be considered as one partition of the environment when there are multiple MGs. We consider each MC to be a greedy client, which means that each MC will try to send as much traffic as it possibly can. In addition, traffic load is only generated from MCs and thus MRs only relay traffic. We also consider only MRs and MCs that initially have at least one path to the MG or in other words we only consider the connected component that contain MG. In addition, MT only works in a single common channel.

C. Algorithm

The overview of our proposed method includes representing our network with G_V and G_{MV}. We then calculate the routing path and generate a routing path graph. Next, we find a set of MRs that are unnecessary to the network and determine, which unnecessary MR should be inactive to provide better performance. The algorithm takes set of all MRs (N_R), set of all MCs (N_C) and MG (n_{GW}) as input and return G_T, which contain active MRs and their respective routing path as output. n_{GW} represents MG of the given network. The algorithm is shown in Algorithm 1.

1) Representing the network: Firstly, to represent our network scenario from the given input (N_R, N_C, n_{GW}), we utilizes modified geometric graph called the multi-tier visibility graph, or G_V. G_V can be represented as $G_V = \{N_R, N_C, E\}$, where N_R is the set of vertices representing MRs, N_C is the set of vertices representing MCs, and E is the set of edges, or set of unordered pair representing connectivity of the network. N_R and N_C are disjoint set and N_C is an independent set that represents the fact that MC cannot connect to other MC. An edge exists between two vertices, MR$_x$ and MR$_y$ if and only if either of the following conditions are satisfied:

Algorithm 1 Select working MRs

```
function ALGORITHM1(N_R, N_C, n_GW)
    Compute G_V, G_MV and G_T
    Find UN
    GlobalBest ← max value
    while UN≠ ∅ do
        LocalBest ← max value
        for n in UN do
            Copy G_V and G_MV to G'_V and G'_MV
            Remove n from G'_V and G'_MV
            Compute G'_{T,n} from G'_V and G'_MV
            if T(BCD(G'_{T,n})) ≤ LocalBest then
                LocalBest ← T(BCD(G'_{T,n}))
                Remember n as the best MR
            end if
        end for
        Remove the best MR from G_V and G_MV
        Compute G_T from G_V and G_MV
        if T(BCD(G_T)) ≤ GlobalBest then
            GlobalBest ← T(BCD(G_T))
            Remember G_T as the best G_T
        end if
        Find new UN
    end while
    return best G_T
end function
```

1) $d(x,y) \leq R_{Tmax} \quad x,y \in N_R$
2) $d(x,z) \leq R_{TC} \quad x \in N_R, z \in N_C$

$d(x,y)$ represents the distance between MR_x and MR_y and R_{TC} is MCs' maximum transmission range. An example of G_V is shown in Fig. 3(a). From G_V, we can construct mesh visibility graph, or G_{MV}. G_{MV} is represented as $G_{MV} = \{N_R, E_M\}$, where E_M can be expressed as the set of unordered pair where each $l_{\{x,y\}}$ in E_M has to satisfied following conditions:

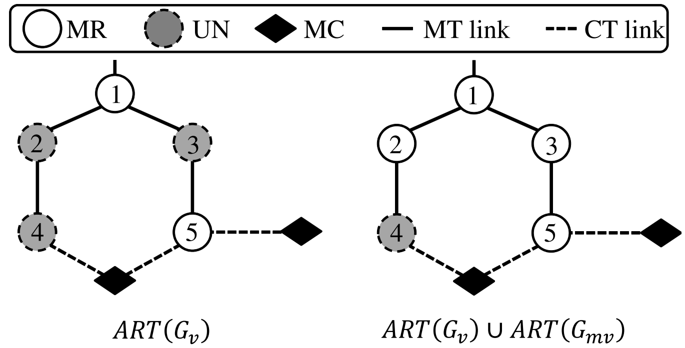
1) $l_{\{x,y\}} \in E$
2) $\text{MR}_x,\ \text{MR}_y \in N_R$

G_{MV} is illustrated in Fig. 3(b) as a graph that is similar to G_V shown in Fig. 3(a), but without any CT components

2) Finding Unnecessary Nodes (UN): With G_V and G_{MV}, it is now possible for us to determine the set of UNs where UNs are nodes that can be removed without breaking any connectivity. In other words, UN is the set of MRs that when removed will not cause G_V and G_{MV} to become disconnected. A set of UNs is defined to be

$$\text{UN} = N_R \setminus [ART(G_V) \cup ART(G_{MV})], \tag{5}$$

where $ART(G)$ is the set of articulation points of graph G. Articulation point, or cut vertex (CV), a graph theory concept that defines a vertex which, when removed, separate the graph into multiple subgraphs. The reasoning behind using CVs of both G_V and G_{MV} is because it is not possible for MR to communicate with another MR through an MC. As illustrated in Fig. 4(a), one can see that when we are using only $ART(G_V)$, MC at the bottom acts as a path connecting MR_4 and MR_5. Therefore, MR_2 and MR_3 are determined as UNs, but since MC cannot relay communications, removing MR_2 or MR_3 would disconnect the network.



(a) (b)

Fig. 4. Illustrates the use of $ART(G_V) \cup ART(G_{MV})$ to find UNs; a) Either MR_2, MR_3 or MR_4 can be removed, but G_V is still connected. Removing MR_2 or MR_3 will isolate MR_4 or MR_5, respectively; b) Only MR_4 can be removed, to still maintain connected graph

Fig. 4(b) illustrated the same scenario with Fig. 4(a) but with using $ART(G_V) \cup ART(G_{MV})$. In this case, the resulting set of UNs is just MR_4, which can be safely removed without disconnecting any MR or MC.

3) Computing Routing Path: In this step, we represent the topology by using topology graph, or G_T to represents the routing path of the graph. Our method does not require a specific routing scheme. However, in this work, we assume the minimum spanning tree routing, because it is a simple and commonly used routing scheme. Therefore, G_T can be calculated by using minimum spanning tree algorithm to find the shortest path to the gateway shown in Fig. 3(c). In additional to the routing path between each MR, G_T also represents the connectivity between MR and MCs. G_T is represented by the notation, $G_T = \{N_R, N_C, E_T, E_{TC}\}$, where E_T is the resulting set of links as an ordered pair $l_{(x,y)}$ from the minimum spanning tree algorithm where x is the parent of y. E_{TC} is a set of ordered pair $l_{(r,c)}$, where r is the closest MR to c and $d(r,c)$ is less than R_{TC}. With routing path established, we can determine R_T of each MR and determine BCD of the network.

4) Selecting active MRs: In this step, we iterate through all MRs in UN to find the MR that should be removed from the network. To achieve this, first G_V and G_{MV} are copied to temporary graphs, denoted by G'_V and G'_{MV} respectively. The MR $\in$ UN within the current iteration, denoted as MR_n is removed from the temporary graphs G'_V and G'_{MV}. From the new temporary graphs, it is possible to compute temporary G_T denoted as $G'_{T,n}$, or the temporary G_T that is computed from G'_V and G'_{MV} without MR_n.

We utilize the CD concept introduced in Section II to calculate the performance of the network by calculating $T(BCD(G_T))$. The potential traffic of m-th MR, or $P(m)$, is the amount of traffic that MR m is trying to send. Since we assume that only MCs generate traffic, we can say that $P(m)$ is equal to the number of MCs that are connecting to MR_m

$$P(m) = |\{l_{(m,c)}\}| \quad c \in N_C, \quad l_{(m,c)} \in E_{TC} \ . \tag{6}$$

Using the potential traffic, or Eq. (6), we can find the value of each link as the sum of the potential traffic for each MR within the subtree rooted at the child MR of the link. The value of

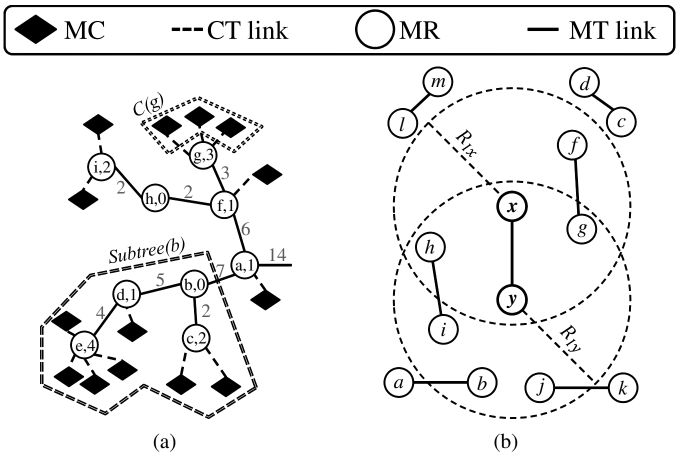


Fig. 5. a) An example of determining potential traffic and value of a link. Vertex's label are node's identifier and its potential traffic, Edge's label is its value; b) An example of determining CD of link $l_{(x,y)}$

$l_{(x,y)}$, or $V(l_{(x,y)})$ can be defined as

$$V(l_{(x,y)}) = \sum_{r \in Subtree(y) \setminus N_C} P(r), \quad (7)$$

where $Subtree(y)$ is the nodes in subtree of G_T rooted at y. An example of determining potential traffic of an MR and value of a link is shown in Fig. 5(a) where the potential traffic of an MR is label within the MR and the value of a link is label on the link. As shown in this figure, the potential traffic of MR$_g$ is equal to the number of MCs connecting to MR$_g$ which is 3. In addition, Fig. 5(a) also shows that $l_{(a,b)}$ is assigned the value of 7. We can see that from the subtree rooted at b, or the child MR of $l_{(a,b)}$, the sum of the potential value of every MR within $Subtree(b)$ is 7 including the potential traffic of the b itself. With potential traffic of each MR and value of each link, it is possible to determine the BCD of the network by using the method described in Section II. However, in a two dimensional space, the use of number of hops to calculate CD does not accurately capture the definition of CD. Therefore, the CD of $l_{(x,y)}$ is determined by any links that have at least one MR within R_{Ix} of MR$_x$ or within R_{Iy} of MR$_y$. This process is shown in Fig. 5(b), where the links that have at least one MR within the interfering range R_{Ix} of MR$_x$ or within R_{Iy} of MR$_y$ include link $l_{(a,b)}$, $l_{(f,g)}$, $l_{(h,i)}$ and $l_{(j,k)}$ With this, we can determine the links that must be inactive in order for $l_{(x,y)}$ to have a successful transmission in two dimensional space.

After calculating $T(BCD(G'_{T,n}))$, the algorithm remember MR$_n$ if the computed $T(BCD(G'_{T,n}))$ is currently the best (the lowest value). The value of $LocalBest$ is used to determine if the current $T(BCD(G'_{T,n}))$ is the best value. The algorithm then iterates through all element element of UN to find the best MR to be removed from the network. Finally, the best MR$_n$ is found, the algorithm remember current $G'_{T,bestMR}$ if $T(BCD(G'_{T,bestMR}))$ is lower than the previous value of $GlobalBest$. This process is then repeats until UN $= \emptyset$, and finally the best G'_T is returned as an output.

IV. Results and Discussions

A. Simulation Setting

Simulation are conducted to show the improvement of the proposed method. The simulations are conducted within a two dimensional playground of a certain area. MRs and MCs are randomly generated within the playground and connectivity are established according to what discussed in Section III. The number of MRs and MCs are $|N_R|$ and $|N_C|$ respectively. The simulation is conducted 50 times with different random seed values to generate different MRs and MCs locations. Simulation parameters are shown in Table II.

TABLE II. Simulation Parameters

Parameters	Value
The number of MR, $\lvert N_R \rvert$	150
The number of MC, $\lvert N_C \rvert$	1000
Area	500 (m) × 500 (m)
R_{Tmax}	80 (m)
R_{TC}	50 (m)

B. Results

In order to show the improvement brought by our algorithm against different random topologies, we conducted 50 experiments with different random seed values that are used to generate the locations of each MR and MC. The simulation parameters are shown in Table. II. The results is shown in Fig. 6 where the improved $T(BCD)$, or scenario with our scheme implemented is shown in red square while the original $T(BCD)$ for the same topology is shown in the corresponding blue diamond. The original implies using all available MRs while the improved implies our method. According to Eq. (4), the lower value $T(BCD)$ means better performance. Therefore, Fig. 6 shows that our algorithm can improve the performance of all the 50 experiments conducted. Next, we calculate the average capacity per MC by using Eq. (4) and Eq. (3). The parameters for Eq. (3) are selected from [8] for 52 Mbps OFDM with CSMA/CA. On the other hand, $T(BCD)$ used is the mean value of 50 simulations results shown in Fig. 6. The calculated capacity per MC is shown in Fig. 7 where the original capacity is shown in dotted blue line, and improved capacity is shown in solid red line. According to results, it can be seen that our scheme can improve the per MC capacity by approximately 10 percent.

To find the relationship between the improvement of capacity per MC and MR density, we conducted an experiment using the same simulation parameters that were given in Table. II. Number of MRs within the simulation area is varied from 100 MRs to 300 MRs, each with 100 different random seed values. The average capacity improvement percentage for each number of MRs is shown in Fig. 8 which shows that the percentage improvement increases with the increasing value of MR density. This improvement increase may come from the fact that with increased MR density, the number of UNs within the network also increases. With more available UNs, it is more likely that the resulting set of MRs would yield more improvement, because there are more available UNs to choose in each iteration. However, according to Fig. 8, the results saturated at $|N_R|$ value of 250 and 300 MRs. This is reasonable, because our algorithm selects MRs set by turning off one MR at a time until it finds the best set. Therefore, the additional MRs in the 300 MRs scenario may become redundant and will be shut off resulting in a similar percentage improvement to the 250 MRs scenario. From this result, it is possible to say that our scheme work well under relatively dense MR density.

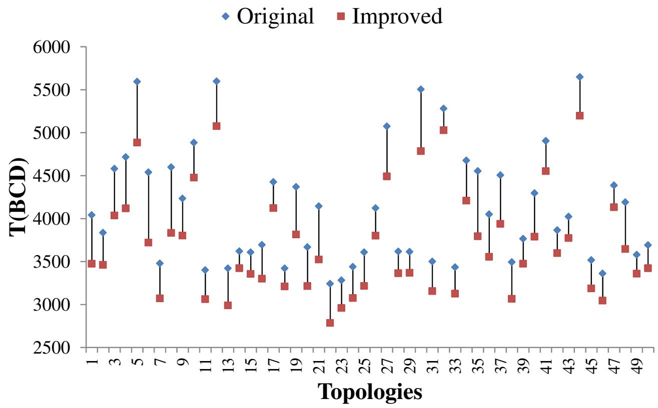


Fig. 6. Improvement of $T(BCD)$ brought by the algorithm for over 50 different randomly generated topologies.

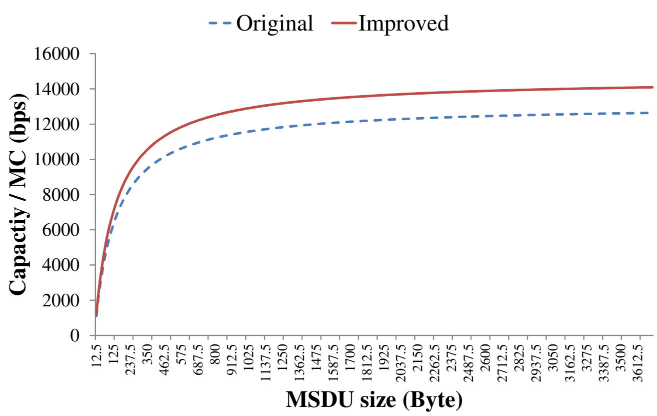


Fig. 7. Average per MC capacity in bps against MSDU size in bytes.

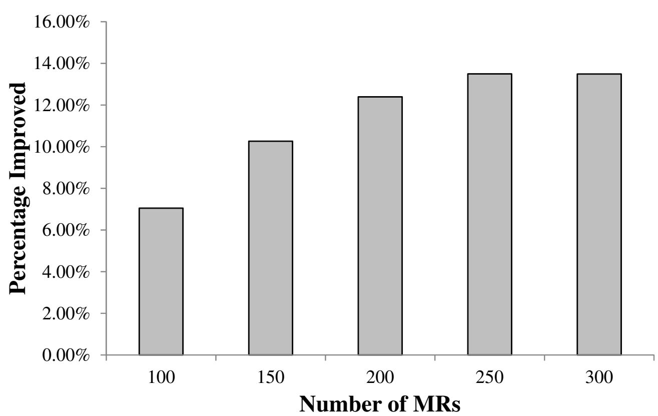


Fig. 8. Average percentage improved for increasing number of MRs within the simulation area.

V. Conclusion

In this paper, we proposed a technique to selects the set of active MRs from all available MRs set that would improve the upper bound throughput of each MC in a randomly deployed and highly dense network. This technique is necessary, because there are many situations where nodes deployment is not controllable. Our contributions in this work include representing multi-tier WMN with graphs and utilizing those graphs to find set of UNs which are the MRs that can be removed from the network without severing existing connectivity of the network. We then proposed an algorithm that goes through the UNs set to determine the MRs that should be removed from the network to improve the overall performance. Finally, we demonstrate the upper bound throughput improvement brought by our algorithm especially in dense network through simulations.

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