International Journal of Innovative
Computing, Information and Control
Volume 8, Number 2, February 2012
 ISSN 1349-4198
pp. 1479–1491

A MULTICAST MECHANISM USING SIGNIFICANCE-BASED AND INTERFERENCE-AWARE ALGORITHM FOR INTRA WIMAX MESH NETWORK

Sheng-Tzong Cheng, Chih-Lun Chou and Gwo-Jiun Horng

Department of Computer Science and Information Engineering
National Cheng Kung University
No. 1, University Road, Tainan 701, Taiwan
stcheng@mail.ncku.edu.tw; { mikechou.3; grojium }@gmail.com

Received November 2010; revised March 2011

Abstract. *IEEE 802.16 WiMAX is a rapidly developing technology for broadband wireless access systems. The IEEE 802.16 MAC layer defines two operational modes, point-to-multipoint (PMP) mode and mesh mode. In the centralized protocol, all resources are controlled by base station (BS). In this work, we propose a novel two-stage scheme for constructing an effective multicast tree. The first stage applies a significance-based algorithm to finding suitable multicast points and constructing effective multicast sub-trees. The second stage applies an interference-aware Steiner tree to connecting the source to each multicast sub-tree. Finally, an algorithm generates the final multicast tree topology. Simulation results reveal that the proposed approach outperforms others in the construction of a multicast tree and significantly reduces the interference of a mesh network.*
Keywords: WiMAX mesh, Multicast tree, Interference-aware, Steiner tree, Significance-based

1. Introduction.

In recent years, the demand for personalized multimedia applications, such as live streaming and VoIP services over wireless networks, has increased. Broadband wireless access can fulfill this increasing demand for multimedia applications. The IEEE 802.16 standard (also known as WiMAX) is currently one of the most active standards for broadband wireless access, and has attracted considerable attention for wireless network applications and related research.

The WiMAX network comprises a single Base Station (BS) and multiple Subscriber Stations (SSs). The BS acts the gateway through which all SSs access the Backhaul network. Each SS can be treated as a single user or an access point that serves multiple users using another network protocol, such as Wi-Fi or Ethernet. The WiMAX standard (IEEE 802.16d) defines two operating modes, which are point-to-multipoint mode (PMP) and mesh mode. In PMP mode, a base station acts as a coordinator and relays all communications to each SS. All SSs can directly connect to BS only through a single-hop wireless link, forming a traditional cellular like network structure. Accordingly, in PMP mode, all SSs are located within the transmission range of BS. However, in mesh mode, all SSs can communicate with either BS or other SSs in a multi-hop manner. Unlike in PMP mode, downlink is not clearly separated from uplink. Since mesh mode can support multi-hop routes, the coverage of the mesh network can be extended more easily and deployment will be much flexible.

This work focuses on mesh mode. In the WiMAX Mesh Mode, scheduling can be either centralized scheduling (CS) or distributed scheduling (DS). Centralized scheduling is similar to scheduling in the PMP mode. BS acts not only as an interface of a backhaul network, but also as a centralized control node in the network. All topological and control-related information can be gathered by BS. Distributed scheduling can be categorized

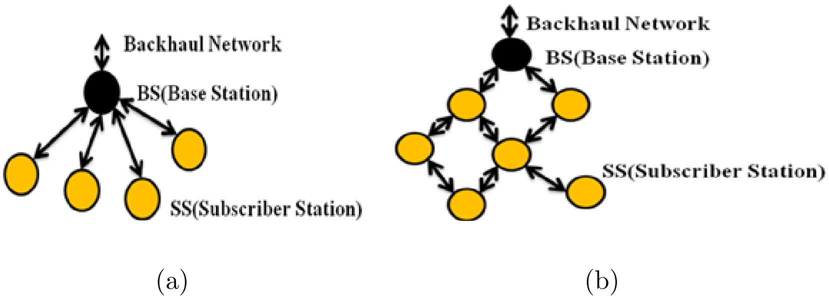


Figure 1. (a) Cellular like PMP mode; (b) mesh mode

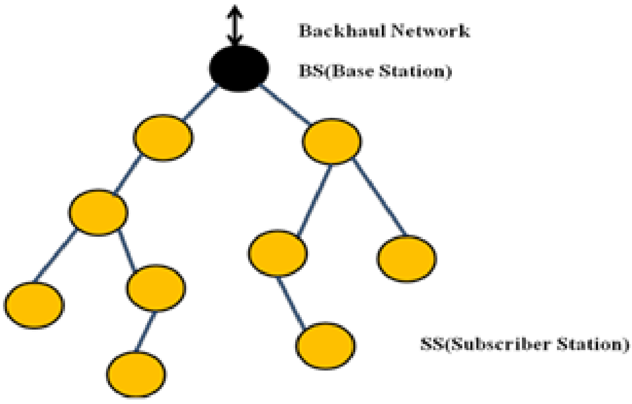


Figure 2. Control tree rooted in BS

into coordinated distributed scheduling and un-coordinated distributed scheduling. In coordinated distributed scheduling, the sender and receiver coordinate using a three-way-handshake to avoid collision. Un-coordinated distributed scheduling is contention-based and applied to transmission. In centralized scheduling, a control tree that is rooted in BS and each SS are established to form the routing path between SSs and BS based on the physical topology shown in Figure 2. For example, when a new node wants to join the mesh network, it will choose a neighbor with a better transmission condition as a sponsor node, and the sponsor node will be the father node in the control tree. BS can receive the network configuration and transmission request from SSs via the control tree.

In the control sub-frame, SSs will send their transmission request with the MSH-CSCH (mesh centralized scheduling) request to BS via the control tree. An SS will send its request to its father node first. After it has collected all of the requests from the child node, the father node adds its request and sends all requests to the upper father node again. In this manner, BS collects all bandwidth requests from SSs, and decides upon the transmission scheduling based on those requests. BS will return the scheduling result through MSH-CSCH to every SS using the control tree. After the slot allocation in the grant message has been received, SS sends or receives data in the appropriate time slot of the data sub-frame. BS will broadcast another MSH-CHCF message to every SS to maintain the control tree topology.

This work focuses on a data multicast intra WiMAX mesh network. The IEEE 802.16 mesh mode does not determine the assignation of mini-slots to various stations, which has become a popular research topic in recent years. However, multicast routing is very effective, especially in a wireless network. Data can be received by many users in the transmission range from a single transmission. Bandwidth resources in a wireless network are limited. To fully utilize the bandwidth resources herein, multicast is applied to transmit data to receivers.

This work proposes a two-stage building tree algorithm to help us build an effective multicast tree. The rest of this article is organized as follows. Section 2 briefly reviews previous studies of related topic. Section 3 presents a detailed proposed scheme. Section 4 analyzes the performance of the proposed scheme. Section 5 presents simulation results and Section 6 draws conclusions.

2. **Related Work.** This section briefly introduces some related works on multicast tree and WiMAX mesh network. Many multicast protocol have been proposed multihop network where node communicate with their neighbor using wireless links. And most of them focus on ad-hoc network. In ad-hoc network, the topology may change quickly, and each node just only knows position information about its neighbor. Flooding message plays an important role in ad-hoc multicast. ODMRP [1] is a mesh-based protocol that uses a forwarding group concept. If the source wants to multicast the data, it broadcasts the Joint-Query to the entire network. When an intermediate node receives a Join-Query packet, it stores the source ID and the sequence number and broadcast again. If a receiver node received Join-Query packet, it replies Join-Reply packet back to the source along with the path of Join-Query packet. And the routing path between source and receiver is established. Swarm intelligence [2] improved the routing path established by flooding. Every receiver periodically sends an ant packet, which is always find whether or not a better routing path exists than the original one. By this manner, an effective multicast tree will be build.

[3] proposed a heuristic algorithm for multicast tree construct in static ad-hoc networks. The algorithm deliver a data packet from a source node to a set of receiver nodes with a minimal transmission time. [5] first prove building an optimal multicast tree is a NP-complete problem. Author proposed a greedy-based heuristic algorithm to find an effective multicast tree. The algorithm can be dividing into two parts. The part one will find optimal multicast subtree in greedy method. The part two will use Steiner tree [6] to find the routing path between source and each subtree. The Steiner tree algorithm time complexity is $O(\mathrm{s}*\mathrm{v}2)$.

Interference is another important issue in WiMAX Mesh network. In [7], a simple heuristic scheduling and routing tree construction algorithms have been proposed to achieve efficient spectral utilization with spatial reuse and also increase the throughput of WiMAX mesh networks.

[9] proposed centralized queue aware routing to solve congestion problem. Beside the father node in control tree, node in mesh network also has a pseudo parent. Assume the transmission condition of father node is bad, so the node can transfer to routing path to pseudo parent, and avoid the congestion problem.

Multicast in WiMAX mesh network are discussed in [11], the author want to offer video on demand service by multicast. However, the multicast tree is just the subtree of original control tree, and multicast tree is branch widely. And also does not mention intra mesh traffic. And [12] also focus on building multicast tree in WiMAX mesh network, the source nodes and receivers are nodes in mesh network. In this paper, the algorithm also has to base on control tree. The source node has to transmit data to BS by the control tree first. And BS will build a multicast tree rooted in itself, then multicast data to receivers. Because the building tree algorithm is based on control tree, the effective of multicast tree also limited by the control tree. Even through many works on multicast tree are discussed as mention above, and there are still some defect. Section 3 will propose a new building tree algorithm for intra WiMAX Mesh network.

3. Proposed Scheme. This section explains in detail the merits of multicast, as well as the difference between a building multicast tree in an ad-hoc network and in a WiMAX mesh network. A two-stage tree-building algorithm for an intra WiMAX mesh network is proposed.

As mentioned in Section 1 WiMAX mesh supports centralized scheduling, and the BS manages all of the topological information and resources. Such an arrangement differs greatly from a traditional ad-hoc network. Since the BS has global information about the whole network, it constructs the multicast tree.

Nevertheless, building multicast tree in a mesh network is still an NP-complete problem. This investigation proposes a two-stage tree-building algorithm to help build an effective multicast tree. The objectives are as follows:

1) Propose a mechanism intra WiMAX Mesh.
2) Use multicast instead of unicast.
3) Distinguish multicast tree from control tree.
4) Minimize the number of nodes in the multicast tree.
5) Reduce the transmission load of the network.

The multicast tree is used for intra-mesh networks. It should not be based on a control tree. Fewer nodes in the multicast tree correspond to greater effectiveness. Fewer intermediate nodes can be used while serving all of the receivers, revealing that the number of data transmitted can be reduced. The goal is to reduce the transmission load of the network, and thus reduce the number of interference nodes when data are transmitted.

The two-stage algorithm has two stages. ***Stage 1*:** Use a significance-based algorithm to find a multicast node and build effective multicast sub-trees. ***Stage 2*:** Build an interference-aware Steiner tree to connect all sub-trees with the source.

In Stage 1, each receiver is initially treated as an independent sub-tree, and Head is used to represent the root of a sub-tree. The significance-based algorithm is proposed to help find a suitable multicast node that can serve more than two Heads. If such a multicast node can be found, then the multicast node is merged with the Head, which can serve as, and form, a new multicast sub-tree. The multicast node will be the root of the new multicast sub-tree. If a routing path between source and each multicast sub-tree cannot be found, then the building tree process will enter Stage 2. In Stage 2, the interference-aware Steiner tree can be used to build a routing path between source and each multicast sub-tree and output the final multicast tree topology.

3.1. **Significance-based algorithm.** In building a multicast tree process, the choice of a suitable multicast node is very important. For example, in Figure 4(a), if node B is chosen as the first multicast node, then nodes A and C have to transmit data to the receiver by unicast, and four transmissions are required to serve all of the receivers. However, nodes A and C can be chosen as a multicast node in Figure 4(b). The total transmission time is then reduced by one third. This example demonstrates importance of finding a suitable multicast node. This study proposes a significance-based algorithm to find suitable multicast nodes.

The proposed algorithm is designed according to several principles to find a suitable multicast node. It starts from the Head with a high hop count, and move gradually toward to the source. A Head with a high hop count is considered as a possible multicast node with a higher priority more likely to be a multicast node. If a Head has more neighbors, then it is more likely to be served by its neighbors, therefore, head with fewer

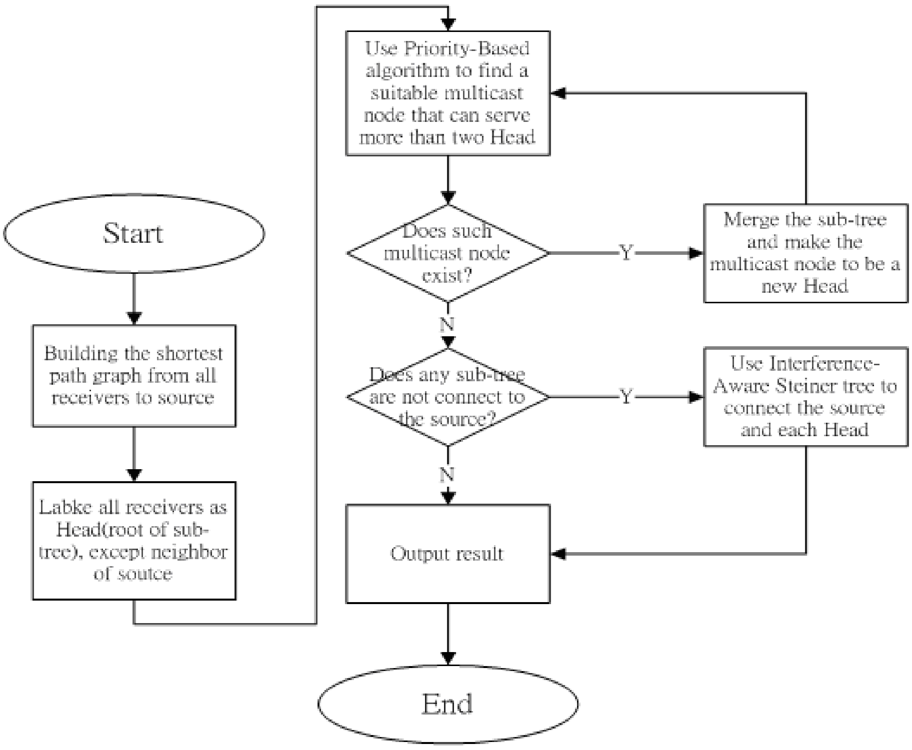
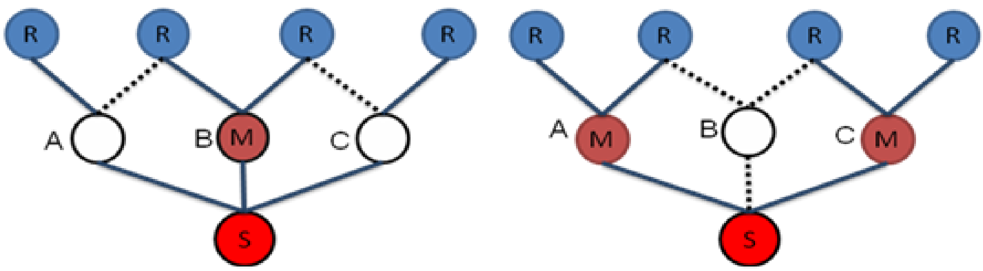


FIGURE 3. Build tree process



(a) (b)

FIGURE 4. (a) B as multicast node; (b) nodes A and C as multicast node

neighbors should be prevented from starving with a higher priority. A sub-tree with more receivers should be saved with a higher priority. A node that can serve more Heads should become a multicast node with higher priority. Based on the aforementioned principle, a mathematical algorithm is formulated. Only the Head (that is root of sub-tree) has a significant value which is given by,

$$\text{significance} = \frac{\text{hop count from } s + \text{Number of receivers node in the subtree}}{\text{Number of neighbors with the same hop count and lower hop count}} \tag{1}$$

The numerator is the hop count of the Head that is associated with the receiver because the process of constructing a multicast tree proceeds from the farthest source to the closest source. Thus, as the number of hops increases, hops are added first to the Multicast Sub-Tree. The number of receivers of Head is considered since it is more important to carry more nodes. The denominator is the number of neighbors on the same level as the Head (which is number of hops) or that number minus one (hop count-1). S-sum (significance sum) equals the total significance value neighbors with the same hop count and a higher hop count. If more than one node has the same S-sum, then choose the node with the fewest hops from the source. The shortest path sub-graph $G(V, E)$ from source to all receivers is built in WiMAX Mesh topology. The Head and neighbor are represented by H and NH, where the *same hop count* $\in j = 1, 2, \ldots J$ and *lower hop count* $\in k = 1, 2, \ldots K$. The S-sum is represented as S_{sum}, where $v \in V$.

$$S_{sum} = \sum_{j=1}^{J} H_{NH_j} + \sum_{k=1}^{K} H_{NH_k} \tag{2}$$

$$\begin{aligned} &\max_{\substack{v \in V \\ v=1}} |S_{sum}| \\ &\text{subject to } v > 1, \quad S_{sum} = \sum_{k=1}^{K} H_{NH_k} \end{aligned} \tag{3}$$

$$H_{NH_k}^{n+1} = H_{NH_k}^{n} - serve(v) + \{v\}, \quad v = \begin{cases} v \neq 1, & H_{NH_k}^{n+1} = H_{NH_k}^{n} - s(v) + \{v\} \\ v = 1, & \text{Connect to the source directly} \end{cases} \tag{4}$$

Algorithm: The shortest path sub-graph from source to all receivers in WiMAX mesh topology

```
Head=all receivers at initial except neighbor of source
repeat
  Calculate the significance of each Head
  For all neighbor of Head in same hop count and lower hop count
     Calculate the S-sum
  Find max S-sum v ∈ V {v serve more than one Head}
     If more than one node with max S-sum
       Choose the node with lower hop count
     End if
     If v found then
        If hop count of v!=1 then
          Head=Head - serve(v) + {v}
        else
          Connect v to source directly and delete it is serve node
          from Head
        End if
     End if
     Until Num (Head) =0 or v=NULL
     If Num (Head) !=0 then
       Calculate the interference value
       Build interference-aware steiner tree among Head and source
     End if
```

Figure 5 is shown an example of a significance-based algorithm. Four receivers exist initially, all of them are labeled Heads. The significance of each Head is then calculated. The significance of D, E, F and G is 3, 1.5, 1.5 and 3 respectively. After the significance

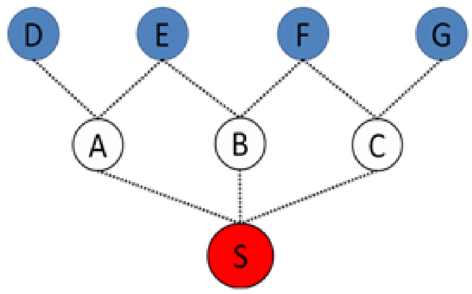


FIGURE 5. Example of significance-based algorithm

value of each Head has been calculated, the node with highest significance sum is identified as the multicast node. The significance value of node C is 4.5, which is the highest value in the topology, and so node C is selected as the multicast node in this round. The overall algorithm process in pseudo code is as follows. The shortest path sub-graph $G(V, E)$ from source to all receivers in WiMAX Mesh topology is built.

3.2. **Interference-aware Steiner tree.** The above sections have concentrated on the significance-based algorithm. In Stage 2, the interference-aware Steiner tree is used to connect source to each head of sub-tree. The Steiner tree is finds a minimal spanning tree, which is useful in minimal cost multicast tree problems. The problem should be re-formulated as one of finding a multicast tree with minimal transmission. However, result very close to the traditional Steiner tree. This section is divided into two part. First, the fact that the interference-aware Steiner tree problem is an NP problem is explained. Second, the algorithm for solving it is introduced.

3.2.1. *Interference-aware Steiner tree NP complete problem proof.* Stage 2 uses an interference-aware Steiner tree to connect source node with each Head of sub-tree. There is a little difference in wireless environment, because of the real wire is not exist. So the problem should be re-formulated to find a multicast with minimal transmission. However, the interference-aware Steiner tree can get very close result to the traditional Steiner tree.

The interference-aware Steiner tree is define as follows: (I) An undirected graph $G = (V, E)$; (II) A subset of the vertices $H \subseteq V$ (each Head of sub-tree); (III) A number $k \in \mathrm{N}$. Find a sub-tree of G that includes all the vertices of H and that contains at most k edges (interference).

An NP-completeness proof for the interference-aware Steiner tree by transforming another known NP-complete problem to it is proposed. The proof will follow step by step the template advised by Garey and Johnson [16] to show that a problem $\prod$ is NP-complete: Step 1. Problem $\prod$ is in NP, Step 2. Choice a known NP-complete problem $\prod'$, Step 3. Construct a transformation f from $\prod'$ to $\prod$, Step 4. Prove that f is a polynomial transformation.

Step 1 will check the interference-aware Steiner tree problem is actually in NP. Assume $\langle G, H, k\rangle \in IAST$, that is, assume the instance $\langle G, H, k\rangle$ reserves a yes answer. In this case, given an hypothetic positive solution $I \subseteq G$, we can check in polynomial time that (1) I is really a tree, it contains no cycles and it is connected; (2) the tree I touches all the nodes (Heads) specified by the set H; (3) the number of edges used by the tree is no more than k (sum of interference).

Interference-aware Steiner tree problem is in NP for sure now and Step 2 will choice a known NP-complete problem. The Exact Cover by 3-Sets problem seems to serve well for the task, X3C is well known NP-complete problems. X3C problem is define as follows: (I) a finite set X with $|X| = 3q$; (II) a collection C of 3-element subsets of X, $C = \{C_1, \ldots, C_n\}, C_i \subseteq X, |C_i| = 3, 1 \leq i \leq n$. X3C will find C contain an exact cover for X, that is, a subcollection $C' \subseteq C$ such that every element of X occurs in exactly one member of C'. Note that, where C' is a solution which $\langle X, C\rangle \in X3C$ then (I) the members of the solution C' form a partition of the set X, (II) $|C'| = q$.

Step 3 will construct a transformation function from X3C to IAST. We use a reduction from X3C to IAST giving a set of rules to build an instance of IAST starting from a generic instance of X3C and prove that such transformation is executable in polynomial time. Given an instance of X3C, defined by the set $X = \{x_1, \ldots, x_{3q}\}$ and a collection of 3-element sets $C = \{C_1, \ldots, C_n\}$, we have to build the IAST instance specifying the graph $G = (V, E)$, the set of nodes H, and the upper-bound on the spanning tree size k, (1) define the set of vertices V as: $V(G) = \{v\} \cup \{c_1, \ldots, c_n\} \cup \{x_1, \ldots, x_{3q}\}$ basically, we put a new node v, a node for each member of C, and a node for each element of X; (2) define the set of edges: $E(G) = \{vc_1, \ldots, vc_n\} \cup \left(\bigcup_{x_j \in C_i} \{c_i x_j\}\right)$ there is an edge from v to each node c_i, and an edge $c_i x_j$ if the element x_j appears into the set c_i of the X3C instance; (3) the terminal nodes set $H \subseteq V$, $H = \{v, x_1, \ldots, x_{3q}\}$; (4) set k equal to $4q$.

It is easy to see that the reduction from X3C to IAST can be done in polynomial time. Now we are going to prove that there exists an interference-aware Steiner tree with no more than k edges if and only if there is an exact cover for the X3C instance of the problem. That is $\langle X, C\rangle$ belongs to X3C if and only if $\langle G, H, k\rangle$ belongs to IAST.

Step 4 will be divided into two parts. Part 1, X3C$\rightarrow$IAST, suppose there is an exact 3-cover C' for the X3C problem. C' uses exactly q subsets. Without loss of generality suppose they are $C_1, \ldots, C_q$. Then, the tree consisting of edges, (1) $vc_1, \ldots, vc_q$; (2) $c_i x_j$, if $x_j \in C_i$ and $1 \leq i \leq q$. That is an interference-aware Steiner tree solving the problem with $q + 3q = 4q = k$ edges. So, if there is an exact 3-cover, then there is an Interference-Aware Steiner tree using no more than k edges.

Part 2, X3C$\leftarrow$IAST, suppose now there exists an interference-aware Steiner tree I with at most $4q$ edges. Since I is a tree, it has at most $4q+1$ nodes. According to the definition of Interference-Aware Steiner tree, I must also touch the terminal nodes $x_1, \ldots, x_{3q}$ and v, so I contain sat most q c-nodes. However, the degree of c-nodes is 3, so it is impossible to hit all the $3qx$-nodes if the tree contains less than $4q+1$ nodes. We conclude that I has exactly $4q$ edges and contains exactly q c-nodes. Without loss of generality suppose these nodes are $c_1, \ldots, c_q$ then the solution C' of the X3C problem is given by the set $C' = \{C_1, \ldots, C_q\}$.

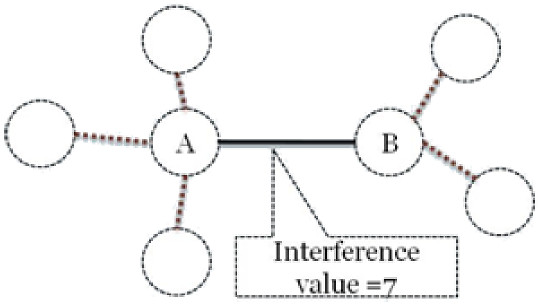


FIGURE 6. Interference-aware value

Algorithm: The interference-aware *steiner tree*

Input: An undirected distance $G(V,E,d)$, V_1 = (source + **Head**) $\subseteq V$

Output: A *steiner tree*, T_n, for G and V_1

Step 1. Construct the complete graph $G(V_1,E_1,d)$, from for G and V_1

Step 2. Find the *minimal spanning tree*, T_1, of G_1
(if there are several *minimal spanning tree*, pick an arbitrary one).

Step 3. Construct the subgraph, G_s, of G by replacing each edge in T_1
by it is corresponding shortest path in G.
(if there are several shortest paths, pick an arbitrary one.)

Step 4. Find the *minimal spanning tree*, T_s, of G_s
(if there are several *minimal spanning tree*, pick an arbitrary one).

Step 5. Construct a steiner tree, T_n from T_s by deleting edges in T_s,
if necessary, so that all the leaves in T_n are steiner points.

3.2.2. *Interference-aware Steiner tree algorithm.* This section attempts to find a Steiner tree with minimal interference. Reducing the interference of transmission would allow is to make spatial utilization more efficient and increase the throughput of the mesh networks. However, the outstanding problem is to calculate the interference value of each link in the WiMAX Mesh network. Consider Figure 6 for example. In Figure 6, when node A wants to transmit data to node B, the neighbors of node A cannot be senders, and neighbors of node B cannot be receivers. Therefore, the interference value associated with the edge between A and B is defined as number of neighbors of node A+ number of neighbors of node B. Accordingly, the interference value of every link is calculated.

4. **Performance Analysis.** This section develops an analytical model to investigate the performance of the proposed scheme.

4.1. **Interference-aware value.** In the algorithm used to build the interference-aware Steiner tree, the distance value is replaced with the interference value. An interference-aware Steiner tree is built between source and each Head. This method is formulated using the following notation,

$$I = N_i + \min \sum_{i=1}^{n} NH_i, \quad \in i = 1, 2, \dots, n \tag{5}$$

$$W_A = \frac{\rho \cdot \chi_A}{NH} \tag{6}$$

$$W_B = \frac{\rho \cdot \chi_B}{NH} \tag{7}$$

$$\begin{aligned} I &= N_i + \min \sum_{i=1}^{2} W_i \cdot NH_i \\ &= N_i + \min\left[|W_A \cdot NH_A| + |W_B \cdot NH_B|\right] \end{aligned} \tag{8}$$

$$\begin{aligned} MMSE &= E\left[(I_y - I_{des})^2\right] \\ &= E\left[\left(N_i + \min \sum_{i=1}^{2} |W_i \cdot NH_i| - P\left[I_{des}|I_y\right]\right)^2\right] \\ &= E\left[\left(N_i + \min \sum_{i=1}^{2} |W_i \cdot NH_i| - \frac{P\left[I_y|I_{des}\right] \cdot P\left[I_{des}\right]}{P\left[I_y\right]}\right)^2\right] \end{aligned} \tag{9}$$

where

I: Interference value;
ρ: Adjustment value of adaptive;
N_i: Number of nodes;
W: Weight value.

4.2. **Minimizing multicast node.** The number of nodes in the multicast tree is an important performance measure of building a multicast tree algorithm. A tree that has fewer nodes involves fewer transmissions. The decision minimal multicast node model that is represented Equation (10). Figure 7 presents a model of system.

$$\begin{aligned} &\text{minimize } \sum_{k=1}^{K} \left[Input\left(H_{NK_k}^{n+1}\right) - des\left(H_{NK_k}^{n+1}\right)\right]^2 \\ &\text{s.t.} \begin{cases} v \neq 1, & H_{NK_k}^{n+1} \\ v = 1, & \end{cases} \end{aligned} \tag{10}$$

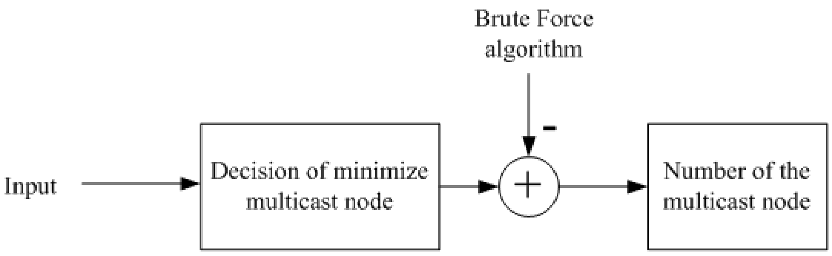


FIGURE 7. The decision of minimize multicast node model

4.3. **Performance of significance-based sub-tree.** The numerator is the hop count of the Head with the receiver because a multicast tree is constructed from the farthest source to the closest source. Therefore, if the number of hops increases, it will be added to Multicast Sub-Tree first. The number of receivers of Head is taken into consideration since it is more important to carry more nodes. Denominator is the neighbor of the same level of Head (the same number of hop count) and the neighbor of the level of Head minus one (the same number of hop count-1).

The numbers of unconnected and connected subtrees are represented by U_i and C_i respectively and the number of receiver is represented by N_R. This probability of success for significance-based of sub-tree is as follows:

$$p_{i,i} = P_{U_i} \cdot \begin{pmatrix} K-i \\ 1 \end{pmatrix} \cdot \left(\frac{NH_k}{N_R}\right) \cdot \left(1 - \frac{NH_k}{N_R}\right)^{K-i-1} + P_{C_i} \cdot \left(1 - \frac{NH_k}{N_R}\right)^{K-i} \tag{11}$$

$$P_{C_i} = \sum_{k=1}^{K} p\left(i, 1, k\right) \tag{12}$$

$$P_{U_i} = 1 - P_{C_i} \tag{13}$$

More neighbors are associated with the reception of more resource channels information. If more nodes are selected, then it is easily to be selected first. The nodes with more neighbors have more resources; the chance will be given to a node with fewest neighbors.

5. **Simulation Results.** This section compares the performance of the proposed algorithm with that of the Pedro M. Ruiz Greedy minimal data overhead algorithm. This algorithm, which was discussed in Section 2, is also a two-stage algorithm. In Stage 1, greedy minimal data overhead algorithm finds the multicast node in a greedy fashion. The node that can serve most receivers is chosen as the multicast node. In Stage 2,

greedy minimal data overhead algorithm uses hop count as the distance form a Steiner tree. The simulation results reveal that proposed algorithm outperforms greedy minimal data overhead algorithm.

Simulation was conducted in VC++. A WiMAX mesh was defined in 802.16d is a FBWA network environment; all nodes in the topology were fixed. Five topologies with 25 fixed nodes were randomly generated such that no topology included an isolated node. To indicate that the proposed algorithm can adapt to various environment, a source and multiple receivers were randomly chosen from these nodes, and simulations were run for 30 rounds.

Figure 8 compares the significance-based algorithm with the greedy algorithm. The y-axis represents the number of receivers, and the x-axis represents the number of remaining unconnected sub-trees. Fewer sub-trees are associated with easier discovery of a suitable for multicast node. The simulation results show that the significance-based algorithm performs better.

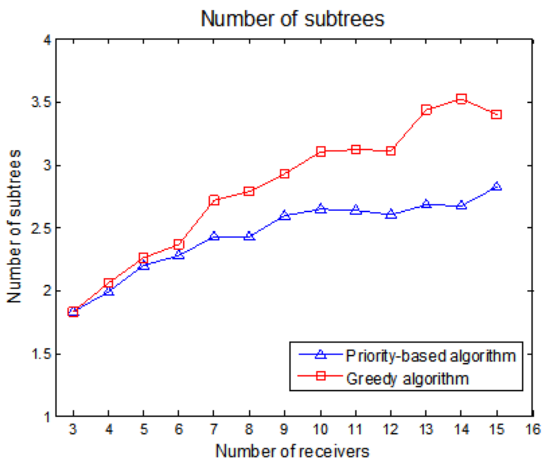


FIGURE 8. Number of subtrees

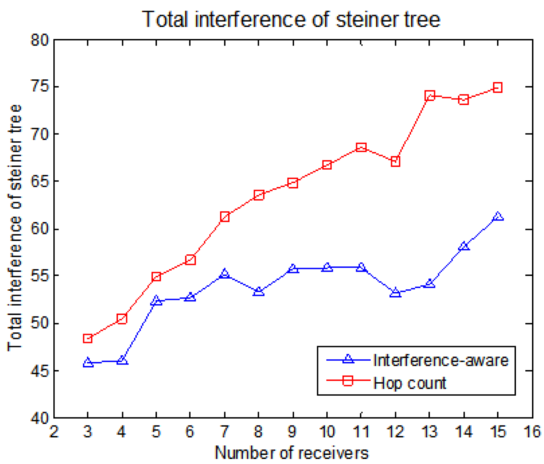


FIGURE 9. Total interference of steiner tree

Figure 9 compares the total interference values of Steiner tree with traditional Steiner tree. A Steiner tree with less interference has better spatial utilization and also enhanced throughput of mesh network. The simulation reveals that the interference-aware Steiner tree has less interference than the Steiner tree based on hop count.

In the simulation, two-stage algorithm is compared with the optimal algorithm. The optimal algorithm is evaluated by considering all possible cases. The time complexity of optimal algorithm is $O(2^n)$. The simulation results show that the multicast tree that is built using the two-stage algorithm has fewer nodes than that built using the greedy minimal data overhead algorithm. Although the performance is still not as good in optimal algorithm, the time complexity of the proposed scheme, $O(n^3)$, is much lower than in the optimal algorithm $O(2^n)$.

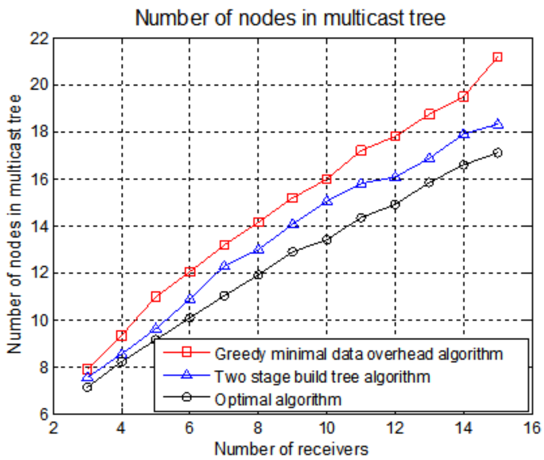


FIGURE 10. Number of nodes in multicast tree

6. **Conclusions.** The WiMAX mesh mode does not define resource managements and allows implementer to describe its required for differentiation from others. Therefore, resource allocation and management are essential in a WiMAX mesh network. Most traditional WiMAX mesh networks are unicast networks. Multicast is an effective method for scheduling real time multimedia traffic. It can be used to transmit data to a group of clients simultaneously.

In this work, we present a novel two-stage scheme for constructing an effective multicast tree. The first stage applies a significance-based algorithm to find suitable multicast points and construct effective multicast sub-trees. The second stage applies an interference-aware Steiner tree to connect the source to each multicast sub-tree. Finally, an algorithm generates the final multicast tree topology. Simulation results reveal that the proposed approach outperforms others in the construction of a multicast tree and significantly reduces the interference of a mesh network, and show the proposed two-stage tree-building algorithm is better than other algorithms is shown as Figure 10.

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