A Multicast Routing Algorithm applied to HIP-multicast Model*

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***Abstract*—Secure HIP-multicast model provides the effective mechanisms of the management, authentication and authorization to group members. But it lacks an appropriate multicast routing algorithm. Here we present a new multicast routing algorithm applied to the HIP-multicast model. The new algorithm decomposes the HIP-multicast tree into a center tree and several sub-trees, and introduces the weight of the nodes and the weight ratio of the links. The results of theory and simulation show that the new algorithm overcomes the shortcomings of traditional multicast routing algorithms and can be applied to the HIP-multicast model.**

Keywords-HIP-multicast; Multicast Routing Algorithm; HIP-MPH; Node weight;Link weight

I. INTRODUCTION

The current IP multicast model based on IGMP has been available for a long time. However, it is excessively loose, non-restrictive and lacking in security. Diot [5] details the deployment issues with the current IP-multicast. Some of these issues include:

·Group management, including authorization for group creation, receiver authorization and sender authorization.

·Multicast address allocation.

·Security, including protection against attacks on multicast communication.

·Access controls.

For solving above problems, Zhu [1][2] presented a new secure HIP-multicast model, which realizes the dynamic management to group members by introducing HIP multicast agent (MA) and two-level administrations. The logical architecture of the HIP-Multicast Model is shown in Figure 1.

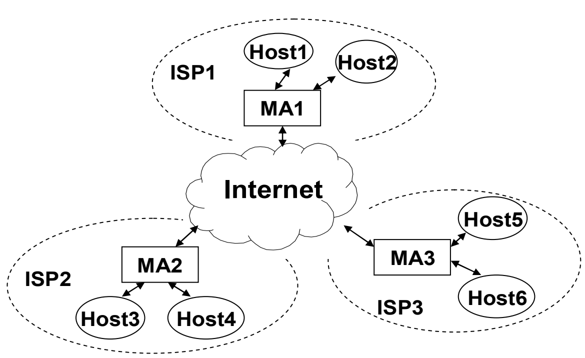

Figure 1 Architecture of HIP-Multicast Model

The new model provides the effective mechanisms of the management, authentication and authorization to group member, which can improve the security of multicast communication. However, although the new model has novel properties that are safe and feasible, it lacks the appropriate multicast routing protocols and spanning tree algorithms. Furthermore, current multicast routing algorithms [3][4][9][10][11][12] based on IP multicast model do not distinguish hosts, multicast members and multicast agents, and they are not suitable for HIP-multicast model. So we present a new multicast routing algorithm applied to HIP-multicast model.

II. MULTICAST ROUTING ALGORITHM APPLIED TO HIP-MULTICAST MODEL

In HIP-multicast model, the multicast agent (MA) plays a key role in multicast groups, and each ISP (Internet Server Provider) needs to have a local server as the MA that is in charge of local management of multicast members, key distribution, traffic forward, billing and auditing. There are two-level administrative areas in HIP-multicast model, first area is composed of Source MA (upstream) and its downstream MAs, and second area is composed of downstream MA and its terminal receivers. The routing spanning trees of each area are independent of each other.

A. Decomposition of HIP-multicast Tree

According to the architecture of HIP-Multicast model, the original routing tree can be decomposed into a center tree and several sub-trees, as shown in Figure 2. Source MA acts as a root of the center tree. Local MA acts as a root of the sub-tree and a leaf of the center tree. Receiver's hosts are the leaves of the sub-tree.

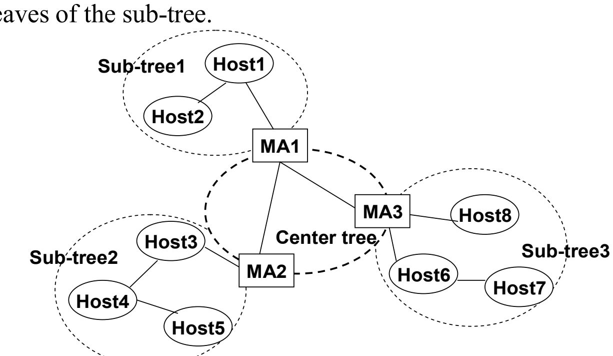

Figure 2 Decomposition of HIP-multicast tree

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The nodes in the two-level trees can be divided into three categories, the junction, endpoint and multicast agent. The different type nodes play different roles in the HIP-multicast tree.

Junction is the host that does not belong to HIP-multicast members in the network. It is responsible for connecting different nodes, and it is not sender or receiver of multicast packets, only in charge of forwarding packets. The importance of junction is lowest.

Endpoint is the host that is a sender or receiver of multicast packets, i.e. multicast member. Endpoint is more important than Junction.

Multicast agent (MA) is the center of multicast group in every HIP-multicast area. Multicast packets from sending endpoints or junctions must go though the multicast agent. The importance of it is highest in three type's nodes.

To facilitate the description of the new algorithm, some definitions are defined as follows:

Definition 1: $\boldsymbol{w(n)}$, the weight of nodes $\boldsymbol{n}$ is defined as the importance of nodes $\boldsymbol{n}$ **(*n*=*u*, *v*, *m*).** The weight of endpoint $\boldsymbol{u}$ is defined as $\boldsymbol{w(u)=1}$. The weight of the junction $\boldsymbol{v}$ is defined as $\boldsymbol{w(v)=k}$ ($0<\boldsymbol{k}<1$), the value $\boldsymbol{k}$ is constant and should be defined based on the actual network environment. The weight of the HIP-multicast agent $\boldsymbol{m}$ should be given as $\boldsymbol{w(m)=Sum(m)}$, where $\boldsymbol{Sum(m)}$ is the number of endpoints in the administrative area of HIP-multicast agent $\boldsymbol{m}$. When an endpoint joins or leaves the multicast group dynamically, $\boldsymbol{w(m)}$ should be increased or decreased accordingly.

Definition 2: The center tree is composed of HIP-multicast agents whose $\boldsymbol{w(m) \geq 1}$ and the links. It is defined as a graph $\boldsymbol{G(E, MA)}$(for short G_{MA}), where $\boldsymbol{MA}$ is the set of multicast agents, $\boldsymbol{E}$ is the set of links and its element $\boldsymbol{e(m_i, m_j)}$ is the cost of the link that connects multicast agents $\boldsymbol{m_i}$ and $\boldsymbol{m_j}$. The source of the center tree (as root) is the local multicast agent of the source, which is also the source (root) of the HIP-multicast tree. When the weight of the multicast agent is zero, it indicates that its all multicast members have left out the sub-tree of the multicast agent, and then the multicast agent should be removed from the center tree.

Definition 3: The sub-tree is composed of the nodes (junctions, endpoints and a multicast agent) and the links. The number of sub-trees is determined by the number of multicast agents whose $\boldsymbol{w(m) \geq 1}$. The sub-tree corresponding to the HIP-multicast agent $\boldsymbol{m_i}$ can be defined as a graph $\boldsymbol{G_i(E, Nd)}$(for short G_i), where $\boldsymbol{Nd}$ is a set of the sub-tree's nodes, E is a set of the links and its element $\boldsymbol{e(n_i, n_j)}$ is the cost of the link that connects nodes $\boldsymbol{n_i}$ and $\boldsymbol{n_j}$.

So, the whole HIP-multicast tree $\boldsymbol{G(E, V)}$ is:

$$G(E,V) = G(E,MA) + \sum_{i=1}^{M} G_i(E,Nd) \tag{1}$$

In which, $\boldsymbol{M}$ is the number of the sub-trees; $\boldsymbol{V}$ is the set of all nodes in HIP-multicast tree.

Theorem 1: HIP-multicast tree can be decomposed of a center tree and several sub-trees, which do not change the functions of the HIP-multicast tree.

Proof: The center tree and sub-trees are constructed in accordance with the HIP multicast routing model, so they do not change paths from source to receivers in the HIP multicast tree. There are not loops in center tree or in sub-trees. The center tree connects sub-tree by way of multicast agent only, so there is not loop between center tree and sub-trees that connect all HIP-multicast members. Therefore, after HIP multicast tree is decomposed of a center tree and several sub-trees, the functions of the HIP multicast tree is not changed.

After HIP multicast tree is decomposed, the construction of the center tree and a sub-tree are independent of each other, and the update of them is also independent of each other when the networks change. The decomposition of HIP-multicast tree is especially appropriate for wide aero network. While the multicast source wants to transmit traffic, it only sends packets to local multicast agent (MA), and then the MA forwards the packets to downstream MA according to the center tree, and downstream MAs forward the packets to their respective receivers by its own sub-tree. For example, in Figure 2, multicast source Host1 sends packets to the MA1 firstly. MA1 forwards the packets to Host2 according to sub-tree G_1. Meanwhile, MA1 also forwards the packets to MA2 and MA3 according to center-tree G_{MA}. Finally, MA2 and MA3 send the packets to their own member hosts according to their sub-tree G_2 and G_3 respectively.

B. Principle of New Algorithm

Next we can design the new algorithms of constructing the center tree and sub-trees. Because of the decomposition of HIP-multicast tree, both the number of nodes in center tree and sub-trees are decrease significantly individually. So the new algorithm is based on the MPH (Minimum Path Cost Heuristic) [8] algorithm, whose performance is better and suitable for the scenario of fewer nodes. But the computation of MPH is lager than other algorithms, and for more fitting MPH for the characteristics of the HIP-multicast tree, we need to decrease its computation and improve on it. The basic steps of original MPH algorithm are given as follows:

(1) Initialization: the source node joins the multicast tree, the rest of nodes are placed in the no-searching set.

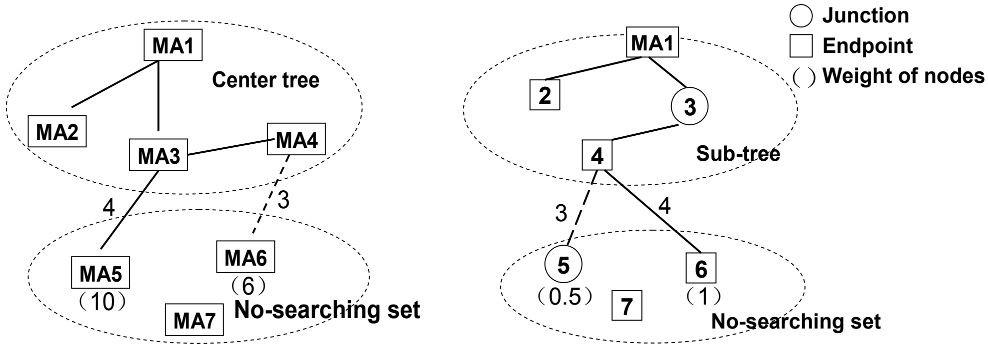
(2) Traverse the multicast tree and the no-searching set, find a node whose cost is least, and add it to the multicast tree.

(3) Repeat steps (2), until the no-searching set is empty, all nodes are added to the multicast tree.

It is obvious that MPH algorithm only considers the link cost regardless of the weight of nodes. If the algorithm is used to construct the HIP-multicast tree directly, then the performance is not very good, and it cannot utilize the benefit of the decomposed tree and the property of the three-type nodes. The following simulation results show that the length and average delay of multicast tree directly used MPH algorithm is longer; and the number of nodes in multicast tree is bigger. Therefore, we propose the weight ratio of the link as a new conception in the improving algorithm.

Definition 4: Let $\boldsymbol{c(n_i, n_j) = e(n_i, n_j)/w(n_j)}$ be the weight ratio of the link of nodes $\boldsymbol{n_i}$ and $\boldsymbol{n_j}$, in which $\boldsymbol{e(n_i, n_j)}$ is a link between node n_i in multicast tree and node n_j in the no-searching set.

When the center tree or sub-tree is constructed, the node whose weight ratio of the link is least should be prior added to corresponding multicast tree from the no-searching set. As in figure 3(a), although the link cost between MA3 and MA5



(a) Center tree (b) Sub-tree

Figure 3 Center tree and sub-tree constructed by HIP-MPH algorithm

is lager than the link cost between MA4 and MA6, the weight ratio of the link between MA3 and MA5 is given as $c(m_3, m_5)=e(m_3, m_5)/w(m_5)=0.4 < 0.5= c(m_4, m_6)$, therefore, MA5 is added to the centre tree rather than MA6. Similarly, as shown in Figure 3(b), node 6 is prior added to the sub-tree.

Thus, the new algorithm will adequately utilize the weight of nodes, the weight ratio of the link and the property of the decomposed tree, and be based on improving MPH algorithm.

C. Pseudo code of New HIP-MPH algorithm

Since the new algorithm is based on HIP-multicast model and improving MPH algorithm, the new algorithm is called as the HIP-MPH algorithm. Pseudo code of algorithm that is used in center tree is given as follow:

(1) Initialize
$MA — m_s \rightarrow Q$;
$m_s \rightarrow V$;
$E \rightarrow \{\ \}$;
(2) while $Q \neq \{\ \}$ Do {//Traverse V and Q, find m_p whose
//weight ratio of link is least, m_o, m_p, m_i, $m_j \in MA$
for V each multicast agent m_i Do {
for Q each multicast agent m_j Do {
$c(m_i, m_j) = e(m_i, m_j)/w(m_j)$;
if $c(m_i, m_j) \leq min$ {
$min=c(m_i, m_j)$; $m_o=m_i$; $m_p=m_j$;
}
}
}
$Q — m_p \rightarrow Q$; $V + m_p \rightarrow V$; //m_p is added to V from Q
$E + e(m_o, m_p) \rightarrow E$;
}
(3) if Q={} Do {
output $T_{center}=(V, E)$; // T_{center} is the center tree.
}
(4) end ;

In which, MA is set of multicast agent, Q is no-searching set, m_s is the source MA node of center tree, V is set of nodes in center tree, E is set of the links(initiate empty).

Similarly, the pseudo-code that is used in sub-trees is given as follow:

(1) Initialize
$H — m_s \rightarrow Q$;
$m_s \rightarrow V$;
$E \rightarrow \{\ \}$;
(2) while $Q \neq \{\ \}$ Do { // Traverse V and Q, find h_p
// whose weight ratio of link is least, h_o, h_p, h_i, $h_j \in H$
For V each node h_i Do {
for Q each node h_j Do {
$c(h_i, h_j) = e(h_i, h_j)/w(h_j)$;
if $c(h_i, h_j) \leq min$ {
$min=c(h_i, h_j)$; $h_o=h_i$; $h_p=h_j$;
}
}
}
$Q — h_p \rightarrow Q$; $V + h_p \rightarrow V$; // h_v is added to V from Q
$E + e(h_o, h_p) \rightarrow E$;
}
(3) if Q={} Do {
output $T_{sub}=(V, E)$; // T_{sub} is the sub-tree
}
(4) end

In which, H is set of nodes of sub-tree, m_s is the source node of sub-tree (local MA), V is set of nodes in sub-tree.

III. SIMULATION AND ANALYSIS

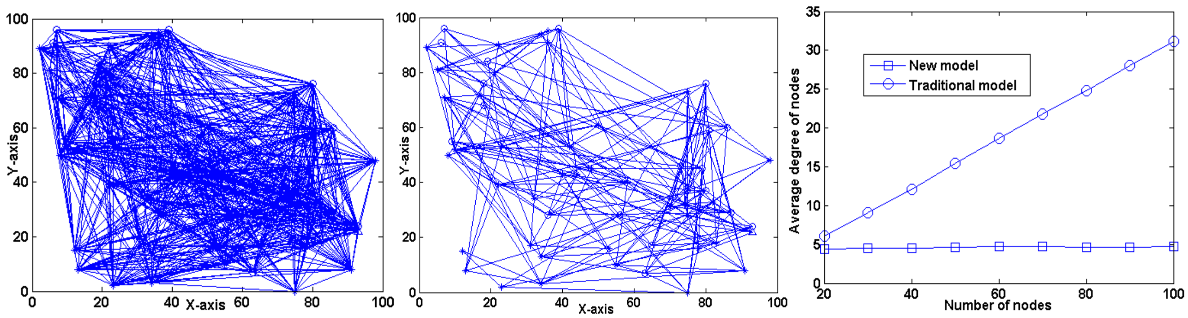
Because the optimal multicast routing algorithm is a complete NP problem in the wide area networks [6], it is difficult to directly give the performance of HIP-MPH algorithm accurately. We use matlab7.0.1 as a simulation tool to verify the effectiveness and practicality of the new algorithm.

A. The Design of the Random network model

In order to get accurate simulation results, we must establish a new appropriate random network model. The traditional random network model [8] is given as follow:

$$p(i,j)=\beta\exp[-d(i,j)/\alpha L_{\max}] \tag{2}$$

Where p(i, j)($0 \le p(i, j) \le 1$) is the probability of the link between the nodes n_i and n_j, d(i, j) is the distance between the nodes n_i and n_j. L_{max} is max distance between any two nodes. α and β are parameters of network. The simulation results of this network model are as in figure 4.



(a) Traditional network model (b) Adjusted network model (c) Comparison of average degree

Figure 4 Comparison of two network model

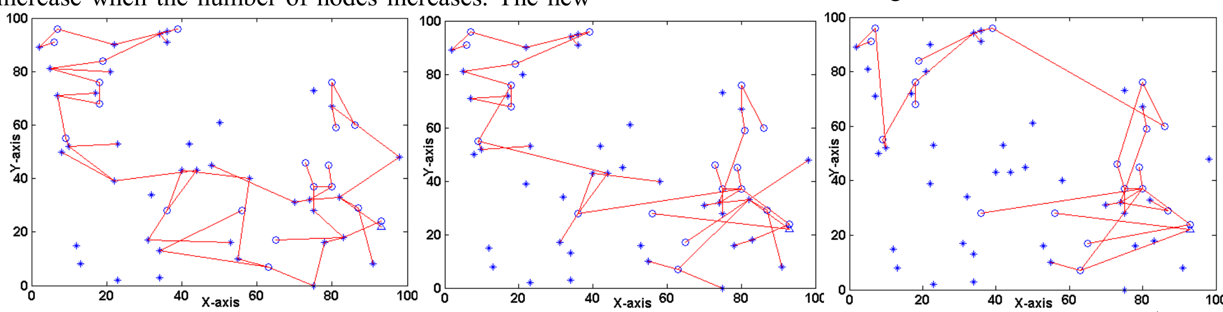
Figure 4(a) and (c) above show that traditional random network model is not appropriate, when the number of nodes is large. Therefore, the equation (2) is adjusted as follow:

$$p(i,j)=\frac{\gamma\beta}{N}\exp[-d(i,j)/\alpha L_{\max}] \tag{3}$$

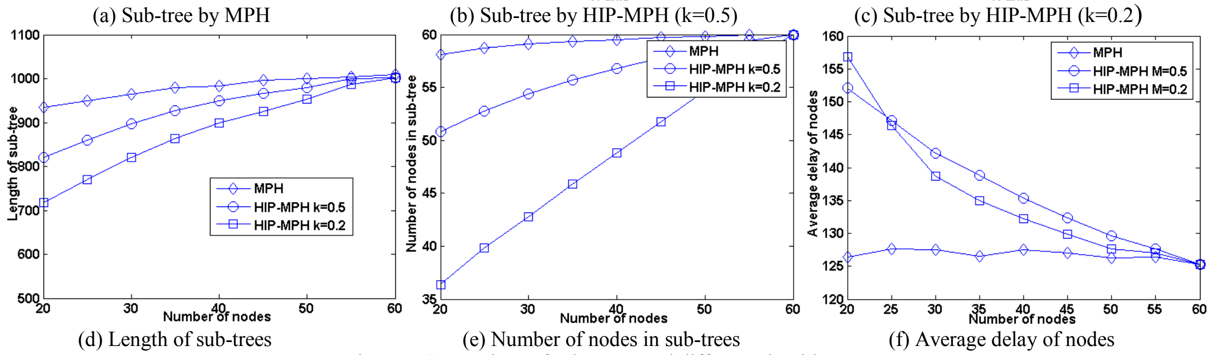
N is the number of the network nodes, γ is a factor. The simulation results of adjusted network model are show in figure 4(b) and (c) below, the average degree of nodes does not increase when the number of nodes increases. The new adjusted network model is more appropriate for wide aero networks than traditional random network model.

B. Simulation and Analysis of sub-trees, center tree and HIP-multicast tree using HIP-MPH algorithm

Now we use the new network model to construct the sub-trees, the centre tree and the HIP-multicast tree in the environment of simulation respectively. The simulation results of them are in figure 5.



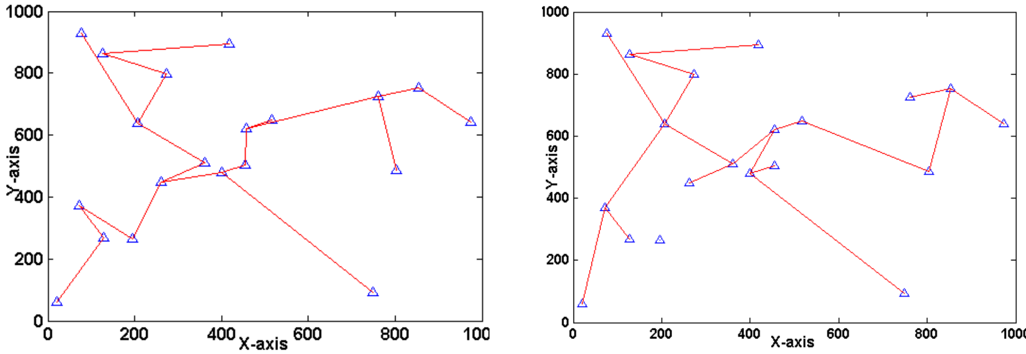
(a) Sub-tree by MPH (b) Sub-tree by HIP-MPH (k=0.5) (c) Sub-tree by HIP-MPH (k=0.2)



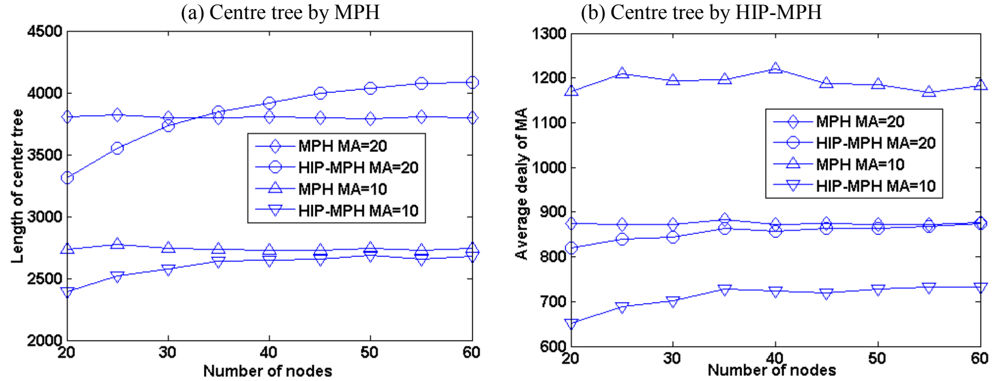
(d) Length of sub-trees (e) Number of nodes in sub-trees (f) Average delay of nodes

Figure 5 Comparison of sub-trees used different algorithms

For the sub-trees in local networks, the nodes are distributed in 100×100 coordinate system randomly. The parameters of simulation are α=0.3, β=0.8, γ=15, L_{max}=144 and N=60. Figure 5(a) (b) (c) are three instances of the sub-trees using MPH, HIP-MPH (the weight of junctions is 0.5 and 0.2) algorithm respectively, where * is denoted as the junction, ○ is denoted as the endpoint, △ is denoted as the multicast agent. Figure 5(d) (e) (f) show that the length of the sub-tree constructed by MPH is longer than by HIP-MPH, the number of nodes in the sub-tree constructed by MPH is larger than by HIP-MPH. However, MPH is superior to HIP-MPH in average delay.



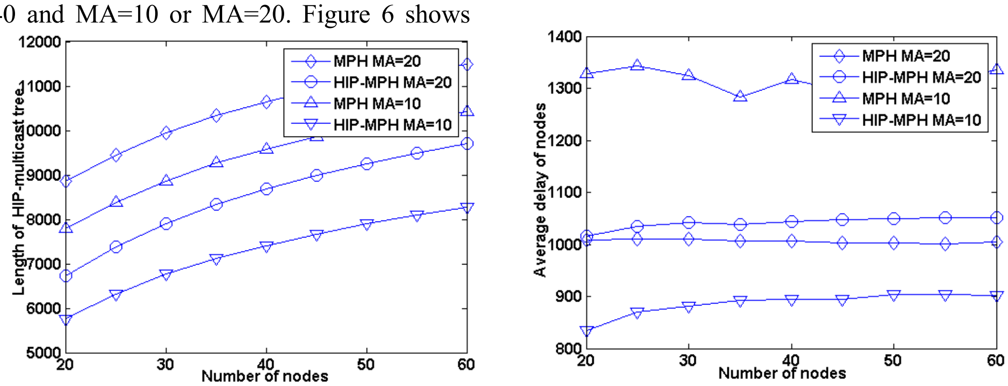
(a) Centre tree by MPH (b) Centre tree by HIP-MPH



(c) Length of centre tree (d) Average delay of MA

Figure 6 Comparison of centre trees used different algorithms

For the center tree in wide aero networks, the multicast agents are distributed in 1000×1000 coordinate system randomly. The parameters of simulation are α=0.3, β=0.8, γ=15, L_{max}=1440 and MA=10 or MA=20. Figure 6 shows that the center tree constructed by MPH is larger than by HIP-MPH. In particular, HIP-MPH can remove MA (203,245) whose weight is zero from the center tree.



(a) Length of HIP-multicast tree (b) Average delay of nodes

Figure 7 Comparison of HIP-multicast tree used different algorithms

HIP-multicast tree is the sum of the center tree and several sub-trees. The length of HIP-multicast tree is the sum of the length of the center tree and sub-trees. From figure 7(a) and (b), we can see the fact that HIP-MPH is more appropriate for HIP-multicast model than MPH. The HIP-MPH can correctly and validly construct the center tree, the sub-tree and the good HIP multicast tree.

C. *Complexity analysis of HIP-MPH algorithm*

For simplifying, we ignored the difference between junctions and endpoints in complexity. Let N be the number of the network nodes and M be the number of multicast agent or the sub-tree. Each node is randomly distributed in the administrative area of MA. The average number of nodes in sub-trees is N/M. The number of searching in sub-tree is $S_{sub}=\sum_{i=1}^{N/M} i(N/M-i)$. The amount of storage is 2N/M. Similarly, the number of searching in center tree is $S_{center}=\sum_{i=1}^{M} i(M-i)$. The amount of storage is 2M. The total number of searching in the tree is

$$S_{HIP-MPH}=S_{center}+MS_{sub} \\ =\sum_{i=1}^{M} i(M-i)+M\sum_{i=1}^{N/M} i(N/M-i) \tag{4}$$

The total amount of storage is 2N/M+2M.

If we do not decompose HIP-multicast tree, then the number of searching is

$$S=\sum_{i=1}^{N} i(N-i) \tag{5}$$

The total amount of storage is 2N.

So that decomposition of HIP-multicast tree can simplify the problem of multicast routing and decrease computation. Because M<<N, the computation of HIP-MPH algorithm is lower than MPH algorithm, and it is more appropriate for HIP multicast model.

IV. CONCLUSION

The new algorithm decomposes the HIP-multicast tree to a center tree and several sub-trees, the nodes in the two-level trees are divided into three categories, the junction, endpoint and multicast agent, and adjusts MPH algorithm according to the weight of nodes and the weight ratio of links. It overcomes the shortcomings of traditional multicast routing algorithms. Theory and simulation results show that it is correct and valid, and can be applied to HIP multicast model.

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