Design and Implementation of Anycast Services in Ad Hoc Networks Connected to IPv6 Networks

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Abstract—The paper proposes a communication model of implementing an Anycast service in an Ad Hoc network which is connected to IPv6 networks where IPv6 nodes can obtain the Anycast service provided by the Ad hoc network. In this model when an Anycast mobile member in an Ad hoc network moves it can keep the existing communications with its corresponding nodes to continue providing the Anycast services with good quality of service to IPv6 nodes. This model creates a new kind of IPv6 address auto-configuration scheme which does not need the address duplication detection. This paper deeply discusses and analyzes the model and the experimental data prove its validity and efficiency.

Index Terms—Ad Hoc, IPv6, Mobile IP, Anycast

I. INTRODUCTION

A Mobile Ad Hoc network (MANET) is an independent mobile wireless multi-hop network without relying on any fixed equipments and each mobile node in a MANET can work as a router. If a node communicates with another node which is not its neighbor node within one-hop scope it must depend on some intermediate nodes to transmit the messages sent by it to the destination node. A MANET has many strengths, such as distribution, dynamic, robustness and mobility, so it has been applied to many special fields, such as cooperated mobile data exchanges and communication systems in war fields, etc.

In the applications of multi-servers whose contents are each other’s mirrors, Anycast is an important mechanism in a MANET as far as the resources, robust and effectivity are concerned. Because the resources owned by a single node in a MANET are limited it is a usual way that a node selects a shortest route to transmit data in order to save powers and network resources and to reduce network blocks. If nodes in MANETs frequently move, which may result in the frequent disconnections between nodes, then Anycast is a good choice to improve the performance of MANETs.

In the Internet Anycast members are fixed nodes whose Unicast addresses are invariable so the route from a client to an Anycast member is changeless. In MANETs a node may move at will the route from a client to an Anycast member is not stable. Therefore, the issue of the high mobility of nodes incurring the frequent changes of routings becomes a focus on how to perform an Anycast service in MANETs.

In this paper, we have proposed a model of implementing an Anycast service in MANETs. The following sections will give a detailed discussion on and analysis of the model.

II. KEY TECHNOLOGY

The protocol stack structure in a MANET is nearly the same as the one in a cable network and both of the protocol stack structures use an IP layer to shield the communications between nodes from heterogeneities of physical channels and media access control layers in different networks. The communication similarity between a MANET and a cable network makes it possible for IPv6 nodes to obtain Anycast services in MANETs. However, a MANET is a self-organization and multi-hop network without a center node and fixed routers, and message exchanges between two nodes must depend on some intermediate nodes to transmit the messages sent by the source node to the destination node. In a traditional network there are fixed routers and a mobile node can not work as a router. Therefore, if we want to perform Anycast services in a MANET connected to an IPv6 network where IPv6 nodes can get the Anycast services then there may exist the following problems.

1) In an IPv6 network the IPv6 routers identified by an Anycast address and its Anycast members are connected to each another through a data link layer, namely, they can reach to each other by one hop. However, in a MANET there is not a data link connection and a mobile node works as a router and message exchanges between two nodes may depend on some intermediate nodes to
transmit the messages sent by the source node to the destination node. Therefore, we need to propose a novel kind of routing method in a MANET so that IPv6 nodes can communicate with Anycast members in MANETs.

2) In general, an Anycast member must first get an IPv6 address and then it can use that IPv6 address to communicate with an IPv6 node. In MANETs when a node moves its IPv6 address may change. Therefore, we must propose a novel address auto-configuration scheme to ensure the communication continuity.

III. RELATED WORK

At the present time some works on how to perform Anycast services in Ad hoc networks have been done. In [2] authors proposed that Anycast services were considered as virtual nodes in network topologies in order to extend such protocols as DSDV(destination-sequenced distance vector) and OLSR(optimized link-state routing protocol) etc to support Anycast services. In [3], authors applied the concept of virtual nodes into DSR, AODV and TORA to support Anycast services. In [4], authors proposed a scheme of implementing Anycast services by aggregating nodes, but they did not describe the scheme in detail and did not analyze performance results in a simulation environment.

In addition some works have been done on the study of the communication between a MANET and an IPv6 network. The references [3] proposed that a mobile node in a MANET used the IPv6 auto-configuration technology to acquire a local link address by which it can connect with the Internet. And the references [1,4] proposed that a mobile node first acquired a global IPv6 address from an Internet ingress gateway and then used the IPv6 address to communicate with the Internet through that Internet ingress gateway. The above two schemes are feasible theoretically but in practice they are very difficult to implement because of the existing problems described in section 2. In addition, in the above two schemes a mobile node in a MANET depended on the duplicate address detection to obtain an IPv6 address, which consumed some network resources and influenced the system performance.

This paper has proposed a model of performing Anycast services in a MANET and an IPv6 network. The references [3] proposed that a mobile node in a MANET used the IPv6 auto-configuration technology to acquire a local link address by which it can connect with the Internet. And the references [1,4] proposed that a mobile node first acquired a global IPv6 address from an Internet ingress gateway and then used the IPv6 address to communicate with the Internet through that Internet ingress gateway. The above two schemes are feasible theoretically but in practice they are very difficult to implement because of the existing problems described in section 2. In addition, in the above two schemes a mobile node in a MANET depended on the duplicate address detection to obtain an IPv6 address, which consumed some network resources and influenced the system performance.

In a MANET, routing protocols may be divided into 2 categories: the routing protocols on an IP layer where a mobile node in a MANET adopts an IP address to identify itself and uses a routing protocol on an IP layer to route messages, and the routing protocols under an IPv6 layer where a mobile node in a MANET adopts an interior address, such as MAC address, to identify itself and uses a routing protocol under an IP layer to route messages. Our model utilizes routing protocols on an IP layer to perform Anycast services in a MANET.

A. Address Structure and Address Assignment

The Anycast address model proposed by IPv6 is totally different from the one recommended by RFC1546. The former suggests that Anycast addresses should be allocated from Unicast addresses so that the Anycast address structure is not distinguishable from the Unicast one, and the latter recommends that Anycast addresses should adopt an independent model. This model chooses the former recommendation. In this model a MANET is connected to an IPv6 network through an IPv6 ingress gateway and from the perspective of the nodes outside a MANET the Anycast address assigned to the IPv6 ingress gateway is equal to its Unicast address.

In this model the Anycast address structure from the perspective of the nodes outside a MANET is shown as follows in table 1:

<table>
<thead>
<tr>
<th>FP</th>
<th>TLA ID</th>
<th>RES</th>
<th>NLA ID</th>
<th>SLA ID</th>
<th>Interface ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>13</td>
<td>8</td>
<td>24</td>
<td>16</td>
<td>64</td>
</tr>
</tbody>
</table>

In the above figure, FP is Anycast format prefix, whose value is the same as the Unicast one; TLA ID is the abbreviation of Top-Level Aggregation Identifier; RES is reserved for future use and must be set to zero; NLA ID is the abbreviation of Next-Level Aggregation Identifier and is used by organizations with a TLA ID to create an addressing hierarchy and to identify sites; SLA ID is the abbreviation of Site-Level Aggregation Identifier and is used by an individual organization to create its own local addressing hierarchy and to identify subnets; Interface ID is the identifier of one interface.

In this model each mobile node has its own IPv6 address and inside a MANET this model adopts the following IPv6 address structure, just as is shown in table 2:

<table>
<thead>
<tr>
<th>FP</th>
<th>TLA ID</th>
<th>RES</th>
<th>NLA ID</th>
<th>SLA ID</th>
<th>Mobile Node Interface ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>13</td>
<td>8</td>
<td>24</td>
<td>16</td>
<td>64</td>
</tr>
</tbody>
</table>

Here, Mobile Node Interface ID is 64-bit long and is divided into 16 levels, each level is identified by a 4-bit identifier and the level of an IPv6 ingress gateway is the uppermost.
In this model when a mobile node requests to join a new MANET it first acquires an IPv6 address and then it may request to join an Anycast group identified by its current IPv6 ingress gateway with an identification of an Anycast address assigned by an authority organization. In general, the IPv6 address of a mobile node is divided into two parts: network prefix and interface ID. This model uses a 64-bit logic address as the interface ID of a mobile node and a 64-bit logic address as the network prefix of a mobile node. The network prefix of the IPv6 address of a mobile node is derived from the network prefix of its IPv6 ingress gateway. In this model a mobile node’s interface ID is divided into 16 levels, each level is identified by a 4-bit identifier and the level of an IPv6 ingress gateway is the uppermost. Therefore, in a MANET each node may contain 15 child nodes at most (except 0000) and the depth of an IPv6 ingress gateway tree (this mode defines that the tree whose root node is an IPv6 ingress gateway is called an IPv6 ingress gateway tree) is 16. For example, if an IPv6 ingress gateway tree is identified by an IPv6 ingress gateway whose Unicast address is 3FE8:1:1:1:1000::/64, then the addresses of its child nodes are 3FE8:1:1:1:x00::, where x=1,2,…,15, just as is shown in figure 1.

B. Acquiring an IPv6 Address

This model defines that an IPv6 ingress gateway can identify an IPv6 ingress gateway tree and it is always the root node of the IPv6 ingress gateway tree, and through the IPv6 ingress gateway the IPv6 nodes can get Anycast services from the Anycast members included in the IPv6 ingress tree.

In this model if a mobile node wants to become an Anycast member it first joins an IPv6 ingress gateway tree to acquire an IPv6 address. A mobile node can acquire an IPv6 address through the following process:

1) The mobile node sends a Join message to its neighbor nodes within one-hop scope;

2) If the neighbor node which receives the message has been marked as a node of an IPv6 ingress gateway tree and the number of its current children is less than 15, then it will return to the mobile node a Response message which includes the assigned IPv6 address;

3) After the mobile node sends the Join message it will set a timer whose time interval may be decided according to the current network status, including the network congestion status and the network bandwidth, etc. After the timer expires, according to the assigned IPv6 address encapsulated in a Response messages the mobile node calculates the distance from the neighbor node sending the Response message to the root node of the IPv6 ingress gateway tree the neighbor node belongs to and then selects the neighbor node with the minimum distance as its father node, records the assigned IPv6 address and the information on its father node, and returns a ACK message to its father node;

4) After the father node receives the ACK message it will add the mobile node into its child list, record the relevant information on the new child, mark the assigned address as Occupied and set a valid time.

Now the mobile node successfully joins an IPv6 ingress gateway tree and acquires its own IPv6 address.

In some extreme situations, if a mobile node which requests to join an IPv6 gateway tree receives no any Response messages during the time interval then it will increase the timer’s time interval by a predefined step and continue sending a Join message to its neighbor nodes until it receives a Response message or the number of the Join messages sent by the mobile node exceeds a predefined threshold.

In fact, the process of a mobile node’s acquiring an IPv6 address is the one of the mobile node’s joining an IPv6 ingress gateway tree, just as is shown in figure 1.

In figure 1, if a mobile node wants to join a MANET then it sends Join messages to its neighbor nodes 3FE8:1:1:1:1220::; 3FE8:1:1:1:1212::, and 3FE8:1:1:1:1211:2000::. After the neighbor nodes receive the Join messages they will return the Response messages to the mobile node which will select the neighbor node 3FE8:1:1:1:1200:: as its father node because the distance from the neighbor node 3FE8:1:1:1:1220:: to the root node of the IPv6 ingress gateway tree is minimum. Thus, the mobile node acquires its IPv6 address 3FE8:1:1:1:1221:: and in the meanwhile it returns an ACK message to its new father node. After the father node receives the ACK message it will add the mobile node into its child node, record the information on the new child node and mark the assigned address as Occupied and set a valid time.

In figure 1, the Anycast address of the IPv6 ingress gateway is 3FE8:1:1:1:: and if the mobile node 3FE8:1:1:1:1221:: wants to join the Anycast group identified by the IPv6 ingress gateway then it will send to its father node an A_Join message which includes a weight value (see section 4.3) and its IPv6 address. After the father node receives the message it still transmits the message to its father node until the message reaches to the IPv6 ingress gateway. After the IPv6 ingress gateway receives the message it will record the IPv6 address of the
mobile node and its weight value and then return an Accept message to the mobile node. The Accept message will return to the mobile node in the same routing as the one the A_Join message passed. After the mobile node receives the Accept message it marks itself as an Anycast member.

In the same way, if an Anycast member wants to leave the Anycast group it belongs to then it will send to its father node a Leave message. After the father node receives the message it still transmits the message to its father node until the message reaches to the IPv6 ingress gateway. After the IPv6 ingress gateway receives the message it will delete the information on the Anycast member and then return an ACK message to the mobile node. The ACK message will return to the Anycast member in the same routing as the one the Leave message passed. After the Anycast member receives the ACK message it deletes its identification as an Anycast member and leaves the Anycast group it belonged to.

In this model, in order to maintain the validity of the topology of an IPv6 ingress gateway tree each mobile node in the IPv6 ingress gateway must periodically send a Query message (the frequency of sending a Query message is partly decided by the current network state, such as the network stability, etc.) to its father node to acquire its current working state. After receiving the message if the father node is in a normal working state then it will reset the mobile node’s valid time and return a Query Response message. If the mobile node does not receive a Query Response message from its father node during the set time it will continue sending a Query message until it receives a Query Response message or the number of the Query messages sent by the mobile node exceeds a predefined value. In the latter situation, the mobile node will mark its father node as an invalid one and it will resend a Join message to its neighbors. In the other hand, if a father node does not receive a Query message from its child node during the child node’s valid time it will delete the information on the child node and release the IPv6 address and other resources occupied by the child node. In the same way, an Anycast member also periodically sends an A_Query message to the IPv6 ingress gateway and notifies that it is working in a normal state. If the IPv6 ingress gateway does not receive an A_Query message from an Anycast member during the set time it will delete the Anycast member’s record.

C. Weight value

This model adopts a weight value mechanism to select an optimal Anycast member. In this model, the IPv6 ingress gateway with an identification of an Anycast address needs to maintain the information records of the corresponding Anycast members, and each record includes one weight-value domain which represents the weight value of the corresponding Anycast member.

In this model through entropy we use the average available bandwidth and the average moving velocity to calculate an Anycast member’s weight value which can indicate the performance of the routing from the IPv6 ingress gateway to the Anycast member.

We assume that the Anycast group identified by an IPv6 ingress gateway is made up of \( N \) Anycast members and the routing \( R_i \) from the IPv6 ingress gateway to the Anycast member \( L \) \((i=1...N)\) contains \( K \) nodes (including the IPv6 ingress gateway and the Anycast member \( L \)). Then, we can use the following equation to calculate the average available bandwidth of the \( k^{th} \) \((k=1...K)\) node \( k \) in \( R_i \):

\[
\bar{B}_{i,k} = (h_i, k\bar{B}_{i,k}, \text{Father} + B_{i,k})/(h_i, k + 1)
\]

Here, \( \bar{B}_{i,k} \) means the average available bandwidth of the node \( k \) in \( R_i \); \( h_i, k \) means the distance (hops) from the IPv6 ingress gateway to the node \( k \) in \( R_i \); \( \bar{B}_{i,k}, \text{Father} \) means the average available bandwidth of the father node of the node \( k \) in \( R_i \); \( B_{i,k} \) means the current available bandwidth of the node \( k \) in \( R_i \). Here, we assume that the average available bandwidth of the father node of the IPv6 ingress gateway is zero.

Thus, we can get the average available bandwidth of the IPv6 ingress gateway and of the Anycast member \( L \) in \( R_i \):

\[
\bar{B}_{i,\text{Root}} = B_{i,\text{Root}} \quad (2)
\]

\[
\bar{B}_{i,k} = (h_i, k\bar{B}_{i,k}, \text{Father} + B_{i,k})/(h_i, k + 1) \quad (3)
\]

In the same way we can use the following equation to calculate the average moving velocity of the node \( k \) in \( R_i \):

\[
\bar{V}_{i,k} = (h_i, k\bar{V}_{i,k}, \text{Father} + V_{i,k})/(h_i, k + 1) \quad (4)
\]

Here, \( \bar{V}_{i,k} \) means the average moving velocity of the node \( k \) in \( R_i \); \( h_i, k \) means the distance (hops) from the IPv6 ingress gateway to the node \( k \) in \( R_i \); \( V_{i,k} \) means the current moving velocity of the node \( k \) in \( R_i \). Here, the average available moving velocities of the father node of the IPv6 ingress gateway and the IPv6 ingress gateway are zero.

Thus, we can get the average available moving velocities of the IPv6 ingress gateway and of the Anycast member \( L \) in \( R_i \):

\[
\bar{V}_{i,\text{Root}} = V_{i,\text{Root}} \quad (5)
\]

\[
\bar{V}_{i,k} = (h_i, k\bar{V}_{i,k}, \text{Father} + V_{i,k})/(h_i, k + 1) \quad (6)
\]

Thus, we can calculate the evaluating value of the routing from the IPv6 ingress gateway to the Anycast member \( L \) with the average available bandwidth and the average velocity of the Anycast member \( L \) in \( R_i \):

\[
\phi_h = \sum_{j=1}^{N} \left(1 - \frac{\bar{V}_{j,k}}{\sum_{j=1}^{N} \bar{V}_{j,k}}\right)
\]

Here, \( \bar{B}_{j,k} \) \((j=1...N)\) means the available average bandwidth of the Anycast member \( L \); \( \bar{V}_{j,k} \) \((j=1...N)\) means the average available moving velocity of the Anycast member \( L \); and \( K_j \) means the total number of the
mobile nodes included in the routing from the IPv6 ingress gateway to the Anycast member $L_i$.

Here, we use the opposite number $(1 - \frac{\bar{V}_{i,k}}{\sum_{j=1}^{N} V_{j,k}})$ of the item $\frac{\bar{V}_{i,k}}{\sum_{j=1}^{N} V_{j,k}}$ to acquire the evaluating value because the more is the average available bandwidth of $R_i$ and the less is the average velocity of $R_i$, the better is the routing performance of $R_i$. Therefore, the larger is the evaluating value $\phi_i$, the better is its routing performance and the better is the quality of the Anycast service provided by the Anycast member $L_i$.

Thus, we can get the weight value of the Anycast member $L_i$ from the following equation:

$$w_i = \frac{\phi_i}{\sum_{k=1}^{N} \phi_k} \quad (8)$$

Here, $w_i$ means the weight value of the Anycast member $L_i$.

For example, in figure 2, the Anycast group identified by the Anycast address of the IPv6 ingress gateway contains 4 Anycast members whose IPv6 addresses are $3FEB:1:1:1:1200::$, $3FEB:1:1:1:1220::$, $3FEB:1:1:1:1221::$ and $3FEB:1:1:1:1210::$. And we assume that the current available bandwidth and the current moving velocity of the node $3FEB:1:1:1:1000::$ are 6Mbps and 0m/s respectively, the current available bandwidth and the current moving velocity of the node $3FEB:1:1:1:1200::$ are $4\text{Mbps}$ and $1\text{m/s}$ respectively, the current available bandwidth and the current moving velocity of the node $3FEB:1:1:1:1220::$ are $4\text{Mbps}$ and $2\text{m/s}$ respectively, the current available bandwidth and the current moving velocity of the node $3FEB:1:1:1:1221::$ are $4\text{Mbps}$ and $3\text{m/s}$ respectively. Then we can get figure 2.

When an IPv6 node sends an Anycast service request message the message will be routed to the IPv6 ingress gateway whose Anycast address identifies the Anycast group. After the IPv6 ingress gateway receives the message it will select an optimal Anycast member according to the weight values of the Anycast members (section 4.3) and then transmit the request message to the optimal member. After the optimal member deals with the message it will return an Anycast service response message with its current IPv6 address as its source address and the Unicast address of the corresponding node as its destination address. In addition, the response message also includes a Home Address Option which records the original Anycast address which was used to establish the connection with the corresponding node. After the IPv6 node receives the response message it will submit the Home Address Option and the destination address of the message to its top layers. In this model the address changes occurring in the IP layer are transparent to the top layers. After the IPv6 nodes receive the Anycast service response message it will add a Routing Header Option into the sequent messages and the content of the Routing Header Option is the current IPv6 address of the optimal Anycast member and the destination address of the sequent messages is still the Anycast address. Thus, the messages sent by the IPv6 node are first routed to the node identified by the Routing Header Option, namely the optimal Anycast member. The entire process is shown in the figure 3(a)(c).

In this model if the optimal Anycast member moves and is disconnected from the IPv6 ingress gateway tree it belonged to then it will resend a Join message to acquire a new IPv6 address in order to continue the existing communication with the IPv6 nodes. When the optimal Anycast member successfully acquires a new IPv6 address it will send an Address-Binding message to its corresponding nodes and notify them of its new IPv6 address. After the corresponding nodes receive the message they will update the content of the Routing Header Option with the new IPv6 address Thus, the messages sent by the corresponding nodes are first routed to the node identified by the new IPv6 address, namely the optimal Anycast member, just as is shown in figure 3(b).
V. RELATED WORK

We have built a simulation environment which has connected a MANET to an IPv6 network and the topology of the simulation environment is shown in figure 1. Each IPv6 node in the simulation environment can get the Anycast services in the MANET through the IPv6 ingress gateway tree it belongs to.

In our experiment, the number of mobile nodes in the MANET can range from 30 to 60, each mobile node is equipped with a wireless network card which is set as an Ad Hoc mode, and an IPv6 ingress gateway is equipped with both a wireless network card and a cable network card to perform the communication between the MANET and the IPv6 network.

In our experiment the range of the radio wave propagation is 180m, the channel capacity is 11Mbs, the size of one packet is 1024bytes, the move velocity of a mobile node ranges from 0 to 10 meters and we adopt the weight value described in section 4.3 as the measurement unit. With a FTP service we test the model and the experimental data indicate that the IPv6 nodes can get Anycast services with high quality even when the Anycast members providing the Anycast services move at will.

In order to test the performance of this model we have compared the performance of this model with the one of OLSR. We define that in OLSR the IPv6 ingress gateway still selects the nearest Anycast member as the optimal Anycast member in terms of the current network topology. We have analyzed the data reception rate, the control message rate and the TRT rate in both this model and OLSR in the following two situations:

1) the number of the mobile nodes changes;
2) the move velocities of mobile nodes change. Here, we define that the packet reception rate means the ratio of the packets received by a receiver to the packets sent by a sender, the control message rate means the ratio of the control packets which are used to perform correct routings in OLSR to the ones to perform correct routing in this model, and the TRT rate means the ratio of the TRT of one kind of Anycast service acquired in this model to the one of the same service in OLSR.

In figure 4 the reception rates in OLSR and this model increase when the number of the mobile nodes increases and they decrease when the move velocities of the mobile nodes increases. The reception rate in this model is always better than the one in OLSR. In figure 5 when the number of mobile nodes grows or the velocities of mobile nodes increase the control message rates in both this model and OLSR enhance. In figure 6 when the number of mobile nodes grows or the velocities of mobile nodes increase the TRT rates in both this model and OLSR enhance. The reasons are as follows:

1) When the move velocities of the mobile nodes increase the network topology frequently changes. And in this model a mobile node which has moved and has been disconnected from its father node can promptly select its current nearest neighbor node as its new father node and rejoin the IPv6 ingress gateway tree to continue the existing communications with its corresponding nodes, therefore in this model it only needs some control message exchanges among the neighbors within one-hop scope to maintain the network topology. When the
network topology frequently changes OLSR has to use a large number of control messages to acquire the updated information on the network topology to ensure the correct communication between nodes. In OLSR the fact that the control messages consume lots of network resources results in the communication delay and the growth of the lost data packets;

2) In this model it does not need to exchange the routing information among the mobile nodes, which saves lots of network resources.

3) A mobile node in a MANET can acquire an IPv6 address without the duplicate address detection, which saves the network resources.

VI. CONCLUSION

Anycast is a new characteristic of IPv6 and can support various kinds of services. This paper have proposed a model of implementing an Anycast service in a MANET and the experimental result indicates that the entire performance of Anycast services performed in this model is better than the one in OLSR. At the present time, the study on Anycast is still at the primary stage there inevitably exist many problems which need further study and analysis.
REFERENCES


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