Chapter 6 Testing and Performance Evaluation

In chapter 5, the implementation of IGMP, PIM-DM and simulation applications for multicast has been discussed. This chapter concentrates on testing and simulation of IP Multicast using PIM-DM. Simulation tests are divided into 2 phases. The first phase is a validation test while the second phase is a performance evaluation test.

Testing has been carried out to validate the operation of the *MulticastdataApp*, the *IPMulticastApp*, the *IGMPv2* and the *PIMDM.* Discussion of the testing will be presented in the first section of this chapter. In the second section, simulation results of the performance evaluation of IP Multicast using PIM-DM are discussed.

6.1 Introduction

A test or simulation is to validate or evaluate a system. In order to achieve the objectives of a testing or simulation, results from the testing or simulation are collected and processed. Basically, in this study, two types of results collecting tools have been employed. The first tool is using log file while the second tool is referring to the presented GUI tables and parameters. Log files are created using the existing *SimLog* class. Meanwhile, the GUI tables and parameters are obtained through *SimParam* category classes.

Before starting any test, a network topology for simulation test purposes is created. All BTEs are assigned a name and a subnet IP address. For all the simulation tests, the BTE is named "BTE*x*", where *x* is a sequence number (such as 1, 2, 3....). For simplification, the subnet IP addresses for B-TEs are set as 1.1.1.0, 2.2.2.0 and so on, depending on the naming sequence for the B-TE.

A name is also given to the routers, link, multicast source and multicast members in the simulation network. The name is in the format of "R*w*", "L*x*", "SG*y*" and "RG*y*-*z*" respectively, where *w*, *x*, *y*, and z are sequence numbers. For examples, R1 is the router number one; L1 is link number one; SG1 is the multicast source group one; and RG1-2 is the second member of multicast group one

The applications simulated in the testing are one-to-many applications. In other words, there is a sending source with multiple members as receiver for one particular multicast group.

6.2 Validation Test

A validation test is carried out to verify the correctness of the implementation of *MulticastdataApp*, *IPMulticastApp*, *IGMPv2*, and *PIMDM*. It is to ensure that the created classes for IGMP, PIM-DM and the simulation application of multicast are running correctly before an actual simulation on IP Multicast using PIM-DM started.

6.2.1 Validation Test for *MulticastdataApp*

Objectives:

- To validate that *MulticastdataApp* could send multicast packets beginning from the specifed start time.
- To validate that *MulticastdataApp* could send multicast packets at specified data rate.
- To validate that *MulticastdataApp* could stop sending multicast packets at the specified stop time.
- To validate that *MulticastdataApp* could send multicast packets to the specified multicast group address.

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.1.

- Input parameter used for *MulticastdataApp* application, SG1.

  -Multicast group address : 230.15.20.1

  -Start time : 2 seconds

  -Data rate : 5 microseconds

  -Stop time : 10 seconds

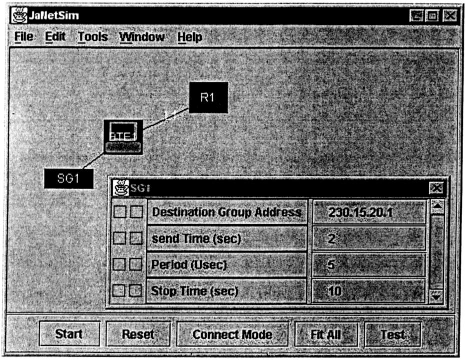


Figure 6.1 Simulation Topology for Validation Test of MulticastdataApp

<u>Results and Analysis:</u>

The events of the *MulticastdataApp* application have been logged into a file. Below are the processed log events.

Time (us)	*Application*	*Event Description*
2000000.0	*SG1*	*START sending multicast packets for 230.15.20.1*
2000005.0	*SG1*	*Send multicast packets for 230.15.20.1*
2000010.0	*SG1*	*Send multicast packets for 230.15.20.1*
2000015.0	*SG1*	*Send multicast packets for 230.15.20.1*

```
2000020.0        SG1      Send multicast packets for 230.15.20.1
2000025.0        SG1      Send multicast packets for 230.15.20.1
...............  ....     ..........
...............  ....     ..........
1.0E7            SG1      STOP sending multicast packets for 230.15.20.1
```

From the above processed log events, a table is created to display the results of simulation.

Table 6.1 Results and Analysis of Validation Test for MulticastdataApp

Expected Results	Collected Results	Remark
Start sending multicast packets beginning at 2 seconds	Multicast packet is sent begin at 2 seconds	Pass
Sending rate is every 5 microsecond one cell, equivalent to 200kbps	Every 5 microseconds one cell is sent	Pass
Stop sending multicast packets at 10 seconds	Multicast packets are stop at 10 seconds	Pass
The multicast packets is sent to group address of 230.15.20.1	The multicast packets is sent to group address of 230.15.20.1	Pass

Conclusions:

MulticastdataApp can work accurately according to the input parameters.

6.2.2 Validation Test for *IPMulticastApp*

Objective:

- To validate that *IPMulticastApp* could join a multicast group at a random time.
- To validate that *IPMulticastApp* could leave a multicast group at a random time.

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.2.

- Input parameter used for the *IPMulticastApp* application, RG1-1, RG-2, and RG1-3

  -Multicast group address : 230.15.20.1

  -Join time : 5 seconds

  -Duration : 10 seconds

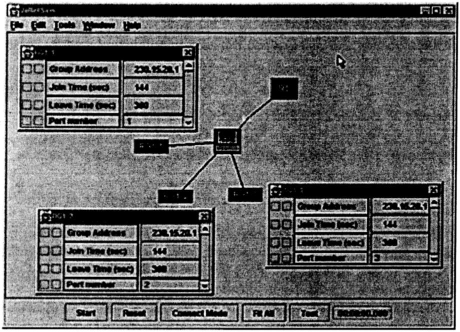


Figure 6.2 Simulation Topology for Validation Test of IPMulticatApp

Results and Analysis:

The join and the leave events in *IPMulticastApp* application have been logged into a file. Below are the processed log events.

Event	Time (us)	Description
JOIN	3.614109258E7	RG1-1 join 230.15.20.1
JOIN	1.1042964119E8	RG1-2 join 230.15.20.1
JOIN	1.3009040085000001E8	RG1-3 join 230.15.20.1
LEAVE	3.2619763914E8	RG1-3 leave 230.15.20.1
LEAVE	5.2859631789E8	RG1-2 leave 230.15.20.1
LEAVE	6.0494842504E8	RG1-1 leave 230.15.20.1

From the processed log events above, a table is created to display the results of simulation.

Table 6.2 Results of Validation Test for IPMulticastApp

IPMulticastApp Application Name	Join Time in Simulation (second)	Leave Time in Simulation (second)	Joining Duration (second)	Joined Multicast Group
RG1-1	36.14	326.20	290.06	230.15.20.1
RG1-2	110.43	528.60	418.17	230.15.20.1
RG1-3	130.09	604.95	474.86	230.15.20.1

Conclusions:

IPMulticastApp performed as expected. It could create a randomly join and leave events and correctly join the specified multicast group.

6.2.3 Validation Test for *IGMPv2*

Objective:

- To validate that *IGMPv2* could perform its behavior according to state diagram correctly.
- To validate that *IGMPv2* could handle IGMP messages correctly.
- To validate that *IGMPv2* could handle join and leave event correctly.
- To validate that *IGMPv2* could handle membership entries correctly.
- To validate that *IGMPv2* could handle timer correctly.

Test 1: Initialization Test

- To validate initialization activities for *IGMPv2*

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.3.

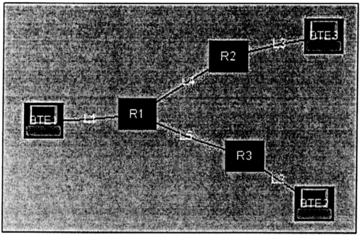


Figure 6.3 Simulation Topology for Initialization of IGMP Test

Results and Analysis:

In the simulation, all events for IGMP have been logged into a file. Below are the processed log events.

Router	Event Description
R1	Send General Query through L5
R1	Start Startup Query Interval
R1	Send General Query through L4
R1	Start Startup Query Interval
R1	Send General Query through L1
R1	Start Startup Query Interval
R2	Send General Query through L4
R2	Start Startup Query Interval
R2	Send General Query through L3
R2	Start Startup Query Interval
R3	send General Query through L2
R3	Start Startup Query Interval
R3	Send General Query through L5
R3	Start Startup Query Interval
R1	Receive Startup Query Timeout
R1	Send General Query through L5

R1	*Start Startup Query Interval Timer*
R1	*Receive Startup Query Timeout*
R1	*Send General Query through L4*
R1	*Start Startup Query Interval Timer*
R1	*Send IGMP message out through L1*
R1	*Receive Startup Query Timeout*
R1	*Send General Query through L1*
R1	*Start Startup Query Interval Timer*
R2	*Send IGMP message out through L4*
R2	*Receive Startup Query Timeout*
R2	*Send General Query through L4*
R2	*Start Startup Query Interval Timer*
R2	*Send IGMP message out through L3*
R2	*Receive Startup Query Timeout*
R2	*Send General Query through L3*
R2	*Start Startup Query Interval Timer*
R3	*Receive Startup Query Timeout*
R3	*Send General Query through L2*
R3	*Start Startup Query Interval Timer*
R3	*Send IGMP message out through L5*
R3	*Receive Startup Query Timeout*
R3	*Send General Query through L5*
R3	*Start Startup Query Interval Timer*
R1	*Send IGMP message out through L5*
R1	*Receive Startup Query Timeout*
R1	*Send General Query through L5*
R1	*Start Query Interval Timer*
R1	*Send IGMP message out through L4*
R1	*Receive Startup Query Timeout*
R1	*S General Query through L4*
R1	*Start Query Interval Timer*
R1	*Send IGMP message out through L1*
R1	*Receive Startup Query Timeout*
R1	*Send General Query through L1*
R1	*Start Query Interval Timer*

```
R2          Receive Startup Query Timeout
R2          Send General Query through L4
R2          Start Query Interval Timer
R2          Send IGMP message out through L3
R2          Receive Startup Query Timeout
R2          Send General Query through L3
R2          Start Query Interval Timer

R3          Receive Startup Query Timeout
R3          send General Query through L2
R3          start Query Interval Timer
R3          Send IGMP message out through L5
R3          receive Startup Query Timeout
R3          send General Query through L5
R3          start Query Interval Timer

BTE2        Receive General Query.
R3          Receive Query
R2          Receive Query
R1          Receive Query
R1          Receive Query
BTE1        Receive General Query
BTE3        Receive General Query
..........  ..........
```

When routers R1, R2, R3 start up, IGMP General Query messages are sent and timers are started. These messages could reach to the respective destinations.

Conclusions:

Initialization part of IGMP, which is implemented in router, can work correctly.

Test 2: Membership Join and Leave Test

- To validate the handling of multicast group joining and leaving process in different scenarios

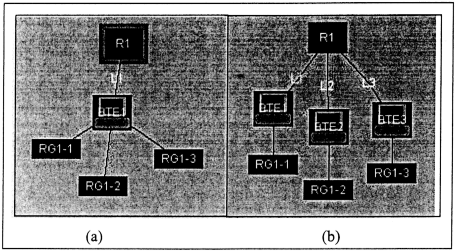


Figure 6.4 Simulation Topology for IGMP Join and Leave Events Test

Scenario 1: More than two members join and leave for a multicast group in one sub network

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.4 (a).
- Input parameter used for the *IPMulticastApp* application, RG1-1, RG-2, and RG1-3

  -Multicast group address : 230.15.20.1

  -Join time : 144 seconds

  -Duration : 360 seconds
- Simulation time : 650 seconds

Results and Analysis:

IGMP Group Table

State	Group Address	Count	Last Report
Idle	230.15.20.1	1	true

IGMP Group Table

State	Group Address	Out Link
Member	230.15.20.1	L1

Figure 6.5 Example of Group Table in BTE1 and R1 for Test in Scenario 1

In the simulation, all events for IGMP have been logged into a file. Below are the processed log events, ascending in time of occurrence.

1) RG1-1 joins multicast group 230.15.20.1.

Component	Event Description
RG1-1	Join group 230.15.20.1
BTE1	Receive event for joining group 230.15.20.1
BTE1	groupTable new entry added for group 230.15.20.1
BTE1	Send Report for group 230.15.20.1 through L1
BTE1	Starts Unsolicited Report Timer
R1	Receive Report for group 230.15.20.1 from L1
R1	groupTable new entry added for (230.15.20.1, L1)
R1	Start Group Membership Interval Timer for (230.15.20.1, L1)
R1	IGMP Notification add for (230.15.20.1, L1)
BTE1	Unsolicited report time out
BTE1	Send Report for group 230.15.20.1 through L1
R1	Receive Report for group 230.15.20.1 from L1

2) Router R1 carries out query process.

Component	Event Description
R1	Receive Query Interval Timeout
R1	Send General Query through L1
R1	Start Query Interval Timer
BTE1	Receive General Query.
BTE1	Start Query Response Interval timer
BTE1	Receive Query Response Timeout
BTE1	Send Report for group 230.15.20.1 through L1
R1	Receive Report for group 230.15.20.1 from L1
R1	Reset Group Membership Interval Timer for (230.15.20.1,L1)

3) Router R1 repeats query process several times.

4) RG1-2 joined multicast group 230.15.20.1. Since there is a member exists for 230.15.20.1, reference count is increased rather than creating a new entry.

Component	Event Description
RG1-2	Join group 230.15.20.1

BTE1	*Receive event for joining group 230.15.20.1*
BTE1	*groupTable reference count increased for (230.15.20.1,L1)*

5) Router R1 repeats query process several times.

6) RG1-3 joins multicast group 230.15.20.1. Since there is two members exist for 230.15.20.1, reference count is increased rather than creates a new entry.

Component	*Event Description*
RG1-3	*Join group 230.15.20.1*
BTE1	*Receive event for joining group 230.15.20.1*
BTE1	*groupTable reference count increased for (230.15.20.1,L1)*

7) Router R1 repeats query process several times.

8) RG1-3 leaves multicast group 230.15.20.1. Since there is two members still stayed for 230.15.20.1, reference count is decreased rather than sends Leave message.

Component	*Event Description*
RG1-3	*Leave group 230.15.20.1*
BTE1	*Receive event for leaving group 230.15.20.1*
BTE1	*groupTable reference count decreased for (230.15.20.1,L1)*

9) Router R1 repeats query process several times.

10) RG1-2 leaves multicast group 230.15.20.1. Since there is one member still stay for 230.15.20.1, reference count is decreased rather than sends Leave message.

Component	*Event Description*
RG1-2	*Leave group 230.15.20.1*
BTE1	*Receive event for leaving group 230.15.20.1*
BTE1	*groupTable reference count decreased for (230.15.20.1,L1)*

11) Router R1 repeats query process several times.

12) RG1-1 leaves multicast group 230.15.20.1. Since there is no more members, a Leave message is sent.

Component	*Event Description*
RG1-3	*Leave group 230.15.20.1*
BTE1	*Receive event for leaving group 230.15.20.1*
BTE1	*Send Leave for group 230.15:20.1 through L1*
R1	*Receive Leave for group 230.15.20.1 from L1*

```
R1          Send Group Specific Query for 230.15.20.1 through L1
R1          Start Last Member Query Interval Timer
BTE1        Receive Group Specific Query for group 230.15.20.1 from L1
R1          Receive Last Member Query Interval Timeout
R1          Send Group Specific Query for 230.15.20.1 through L1
R1          Start Last Member Query Interval Timer
BTE1        Receive Group Specific Query for group 230.15.20.1 from L1
R1          Receive Last Member Query Interval Timeout
R1          Group (230.15.20.1, L1) has no member exist
R1          IGMP Notification remove for (230.15.20.1, L1)
```

Scenario 2: More than two members join and leave for different multicast group in one sub network

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.4(a) with RG1-2 and RG1-3 are replaced by RG2-1 and RG3-1 respectively.
- Input parameter used for *IPMulticastApp* application, RG1-1, RG2-1, and RG3-1.

Table 6.3 Input Parameters for Scenario 2

Input Parameters	RG1-1	RG2-1	RG3-1
Multicast group address	230.15.20.1	235.45.63.2	236.30.12.3
Join time seconds	144	145	143
Duration seconds	360	361	159

- Simulation time : 650 seconds

Results and Analysis:

Basically, almost all the events occurred are similar to the events recorded in the testing for scenario 1, except the handling of join and leave event for three different multicast groups. Since there is one member each for a multicast group, three entries are created for each join event in BTE1 and R1. Leave message is sent for each leave event. Besides, IGMP notification add and remove are triggered for each member join and leave rather than only one as happens in scenario 1.

IGMP Group Table

State	Group Address	Count	Last Report
Delaying	230.15.20.1	1	true
NonMember	236.30.12.3	0	true
Delaying	235.45.63.2	1	true

IGMP Group Table

State	Group Address	Out Link
Member	230.15.20.1	L1
NonMember	236.30.12.3	L1
Member	235.45.63.2	L1

Figure 6.6 Example of Group Table in BTE1 and R1 for Test in Scenario 2

In the simulation, all events for the IGMP have been logged into a file. Only important log events and main differences with scenario 1 are presented in section below. Processed log events are ascending in time of occurrence.

1) RG1-1 joins multicast group 230.15.20.1.

Component	*Event Description*
RG1-1	*Join group 230.15.20.1*
BTE1	*Receive event for joining group 230.15.20.1*
BTE1	*groupTable new entry added for group 230.15.20.1*
BTE1	*Send Report for group 230.15.20.1 through L1*
BTE1	*Starts Unsolicited Report Timer*
R1	*Receive Report for group 230.15.20.1 from L1*
R1	*groupTable new entry added for (230.15.20.1, L1)*
R1	*Start Group Membership Interval Timer for (230.15.20.1, L1)*
R1	*IGMP Notification add for (230.15.20.1, L1)*
BTE1	*Unsolicited report time out*
BTE1	*Send Report for group 230.15.20.1 through L1*
R1	*Receive Report for group 230.15.20.1 from L1*

2) RG1-1 joins multicast group 236.30.12.3.

Component	*Event Description*
RG1-1	*Join group 236.30.12.3*
BTE1	*Receive event for joining group 236.30.12.3*

BTE1	*groupTable new entry added for group 236.30.12.3*
BTE1	*Send Report for group 236.30.12.3 through L1*
BTE1	*Starts Unsolicited Report Timer*
R1	*Receive Report for group 236.30.12.3 from L1*
R1	*groupTable new entry added for (236.30.12.3, L1)*
R1	*Start Group Membership Interval Timer for (236.30.12.3, L1)*
R1	*IGMP Notification add for (236.30.12.3, L1)*
BTE1	*Unsolicited report time out*
BTE1	*Send Report for group 236.30.12.3 through L1*
R1	*Receive Report for group 236.30.12.3 from L1*

3) RG2-1 joins multicast group 235.45.63.2.

Component	*Event Description*
RG1-1	*Join group 235.45.63.2*
BTE1	*Receive event for joining group 235.45.63.2*
BTE1	*groupTable new entry added for group 235.45.63.2*
BTE1	*Send Report for group 235.45.63.2 through L1*
BTE1	*Starts Unsolicited Report Timer*
R1	*Receive Report for group 235.45.63.2from L1*
R1	*groupTable new entry added for (235.45.63.2, L1)*
R1	*Start Group Membership Interval Timer for (235.45.63.2, L1)*
R1	*IGMP Notification add for (235.45.63.2, L1)*
BTE1	*Unsolicited report time out*
BTE1	*Send Report for group 235.45.63.2 through L1*
R1	*Receive Report for group 235.45.63.2 from L1*

4) RG3-1 leaves multicast group 236.30.12.3. Since there are no more members, a Leave message is sent.

Component	*Event Description*
RG1-3	*Leave group 236.30.12.3*
BTE1	*Receive event for leaving group 236.30.12.3*
BTE1	*Send Leave for group 236.30.12.3 through L1*
R1	*Receive Leave for group 236.30.12.3 from L1*
R1	*Send Group Specific Query for 236.30.12.3 through L1*
R1	*Start Last Member Query Interval Timer*

BTE1	*Receive Group Specific Query for group 236.30.12.3 from L1*
R1	*Receive Last Member Query Interval Timeout*
R1	*Send Group Specific Query for 236.30.12.3 through L1*
R1	*Start Last Member Query Interval Timer*
BTE1	*Receive Group Specific Query for group 236.30.12.3 from L1*
R1	*Receive Last Member Query Interval Timeout*
R1	*Group (236.30.12.3, L1) has no member exist*
R1	*IGMP Notification remove for (236.30.12.3, L1)*

5) RG1-1 leaves multicast group 230.15.20.1. Since there are no more members, a Leave message is sent.

Component	*Event Description*
RG1-3	*Leave group 230.15.20.1*
BTE1	*Receive event for leaving group 230.15.20.1*
BTE1	*Send Leave for group 230.15.20.1 through L1*
R1	*Receive Leave for group 230.15.20.1 from L1*
R1	*Send Group Specific Query for 230.15.20.1 through L1*
R1	*Start Last Member Query Interval Timer*
BTE1	*Receive Group Specific Query for group 230.15.20.1 from L1*
R1	*Receive Last Member Query Interval Timeout*
R1	*Send Group Specific Query for 230.15.20.1 through L1*
R1	*Start Last Member Query Interval Timer*
BTE1	*Receive Group Specific Query for group 230.15.20.1 from L1*
R1	*Receive Last Member Query Interval Timeout*
R1	*Group (230.15.20.1, L1) has no member exist*
R1	*IGMP Notification remove for (230.15.20.1, L1)*

6) RG2-1 leaves multicast group 235.45.63.2. Since there are no more members, a Leave message is sent.

Component	*Event Description*
RG1-3	*Leave group 235.45.63.2*
BTE1	*Receive event for leaving group 235.45.63.2*
BTE1	*Send Leave for group 235.45.63.2 through L1*
R1	*Receive Leave for group 235.45.63.2 from L1*
R1	*Send Group Specific Query for 235.45.63.2 through L1*
R1	*Start Last Member Query Interval Timer*
BTE1	*Receive Group Specific Query for group 235.45.63.2 from L1*

```
R1          Receive Last Member Query Interval Timeout
R1          Send Group Specific Query for 235.45.63.2 through L1
R1          Start Last Member Query Interval Timer
BTE1        Receive Group Specific Query for group 235.45.63.2 from L1
R1          Receive Last Member Query Interval Timeout
R1          Group (235.45.63.2, L1) has no member exist
R1          IGMP Notification remove for (235.45.63.2, L1)
```

Scenario 3: More than two sub networks join and leave for similar group

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.4(b).
- Input parameter used for *IPMulticastApp* application, RG1-1, RG-2, and RG1-3
  - -Multicast group address : 230.15.20.1
  - -Join time : 144 seconds
  - -Duration : 360 seconds
- Simulation time : 650 seconds

Results and Analysis:

IGMP Group Table

State	Group Address	Out Link
NonMember	230.15.20.1	L1
NonMember	230.15.20.1	L1
NonMember	230.15.20.1	L3

Figure 6.7 Example of Group Table in R1 in Test for Scenario 3

In this scenario, each member for multicast group 230.15.20.1 exists in different sub network. Basically, all the events occurred are almost similar to the events recorded in testing for scenario 2, except the handling of join and leave event for each member, which occurs in respective sub network. This means RG1-1 reports to BTE1, RG1-2 reports to BTE2, and RG1-3 reports to BTE3, during the events of joining and leaving. In R1, there are three entries created rather than one as what has happened in scenario 1. Furthermore, IGMP Notification Add and Remove are triggered for each joining and leaving events. This is because the three members for 230.15.20.1 come from different sub network.

Stated below is the events log during joining events, particularly concentrated on the handling of multicast group membership entry.

1) RG1-1, RG1-2, and RG1-3 join group 230.15.20.1.

```
Component   Event Description
RG1-1       Join group 230.15.20.1
BTE1        Receive event for joining group 230.15.20.1
BTE1        groupTable new entry added for group 230.15.20.1
R1          groupTable new entry added for (230.15.20.1, L1)
R1          IGMP Notification add for (230.15.20.1, L1)
RG1-2       Join group 230.15.20.1
BTE2        Receive event for joining group 230.15.20.1
BTE2        groupTable new entry added for group 230.15.20.1
R1          groupTable new entry added for (230.15.20.1, L2)
R1          IGMP Notification add for (230.15.20.1, L2)
RG1-3       Join group 230.15.20.1
BTE3        Receive event for joining group 230.15.20.1
BTE3        groupTable new entry added for group 230.15.20.1
R1          groupTable new entry added for (230.15.20.1, L3)
R1          IGMP Notification add for (230.15.20.1, L3)
```

2) RG1-1, RG1-2, and RG1-3 leave group 230.15.20.1.

```
Component   Event Description
RG1-3       Leave group 230.15.20.1
BTE3        Receive event for leaving group 230.15.20.1
R1          Receive Leave for group 230.15.20.1 from L3
R1          Group (230.15.20.1, L3) has no member exist
R1          IGMP Notification remove for (230.15.20.1, L3)
RG1-2       Leave group 230.15.20.1
BTE2        Receive event for leaving group 230.15.20.1
R1          Receive Leave for group 230.15.20.1 from L2
R1          Group (230.15.20.1, L2) has no member exist
R1          IGMP Notification remove for (230.15.20.1, L2)
```

```
RG1-1        Leave group 230.15.20.1
BTE1         Receive event for leaving group 230.15.20.1
R1           Receive Leave for group 230.15.20.1 from L1
R1           Group (230.15.20.1, L1) has no member exist
R1           IGMP Notification remove for (230.15.20.1, L1)
```

<u>Scenario 4: More than two sub networks join and leave for different group</u>

<u>Testing or Simulation Environment:</u>

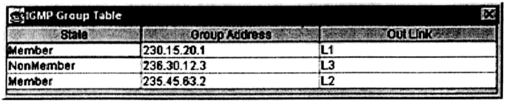
- A network topology is created as shown in Figure 6.4(b) with RG1-2 and RG1-3 are replaced by RG2-1 and RG3-1 respectively.
- Input parameter used for *IPMulticastApp* application, RG1-1, RG2-1, and RG3-1.

Table 6.4 Input Parameters for Scenario 4

Input Parameters	RG1-1	RG2-1	RG3-1
Multicast group address	230.15.20.1	235.45.63.2	236.30.12.3
Join time seconds	144	145	143
Duration seconds	360	361	159

- Simulation time : 650 seconds

<u>Results and Analysis:</u>


IGMP Group Table

State	Group Address	Out Link
Member	230.15.20.1	L1
NonMember	236.30.12.3	L3
Member	235.45.63.2	L2

Figure 6.8 Example of Group Table in R1 in Test for Scenario 4

In this scenario, each different sub network has different member of multicast group. In general, all the occurred events are almost similar to the events that are recorded in testing for scenario 3, different entries are created for different multicast group in BTEs and R1. When a new member joins a multicast group, an entry is created. Figure 6.5 shows the examples of the membership entry for the scenario.

Conclusions

IGMP join and leave handling can work correctly. Indirectly, this means handling of message, IGMP notification and timer also working accurately. Hence, IGMP is validated.

6.2.4 Validation Test for *PIMDM*

Objective:

- To validate that *PIMDM* could perform correctly according to the process flow
- To validate that *PIMDM* could handle PIM-DM messages correctly.
- To validate that *PIMDM* could perform neighbor handling correctly.
- To validate that *PIMDM* could handle forwarding multicast packets correctly.
- To validate that *PIMDM* could handle timer correctly.

Test 1: Initialization and Neighbor Test

- To validate initialization activities for *PIMDM*
- To validate neighbor handling

Testing or Simulation Environment:

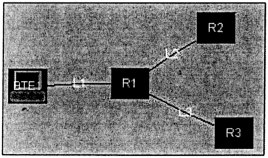


Figure 6.9 Simulation Topology for PIMDM Initialization Test

- A network topology is created as shown in Figure 6.9.

Results and Analysis:

In the simulation, all events for PIM-DM have been logged into a file. Below are the processed log events.

Component	*Event Descriptions*
R1	*Send PIM-DM Hello message through L3*
R2	*Send PIM-DM Hello message through L2*
R1	*Send PIM-DM Hello message through L1*
R1	*Send PIM-DM Hello message through L2*
R3	*Send PIM-DM Hello message through L3*
R1	*Send PIM-DM Hello message through L3*
R2	*Send PIM-DM Hello message through L2*
R1	*Send PIM-DM Hello message through L1*
R1	*Send PIM-DM Hello message through L2*
R3	*Send PIM-DM Hello message through L3*
…………	………………

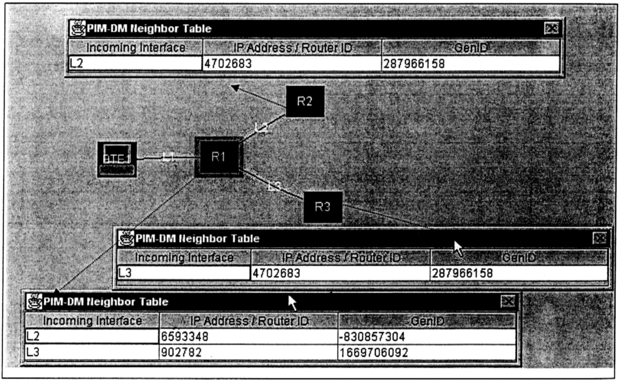


Figure 6.10 Examples of PIM-DM Neighbor Table for Test 1

Routers R1, R2 and R3 send PIM-DM Hello messages through every interface and construct a neighbor table, which store the information of PIM-DM neighbors. Figure 6.10 shows the example of the PIM-DM neighbor table for R1, R2, and R3.

Conclusions

Initialization part of *PIMDM* as well as neighbor handling can work correctly.

Test 2: Tree Establishment and Multicast Packets Forwarding Test

- To validate that *PIMDM* could establish multicast tree correctly
- To validate that *PIMDM* could forward multicast packets
- To validate that members of a multicast group could receive multicast packets correctly

Scenario 1: One Multicast Group

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.11.

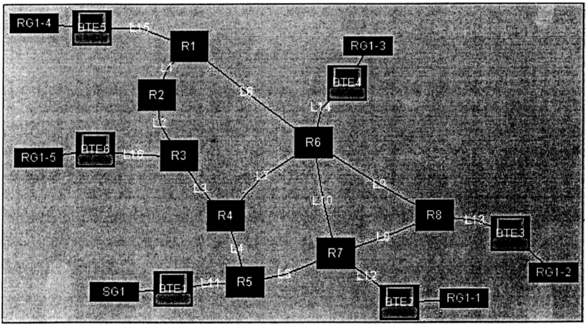


Figure 6.11 Simulation Topology for Tree Establishment and Multicast Packets Forwarding Test in Scenario 1

- Input parameter used for *IPMulticastApp* application, RG1-1, RG-2, RG1-3, RG1-4 and RG1-5

  -Multicast group address : 230.15.20.1

  -Join time : 144 seconds

  -Duration : 300 seconds

- Input parameter used for *MulticastdataApp* application, SG1.
  - -Multicast group address : 230.15.20.1
  - -Start time : 2 seconds
  - -Data rate : 800000 microseconds
  - -Stop time : 600seconds
- Simulation time : 650 seconds

<u>Results and Analysis:</u>

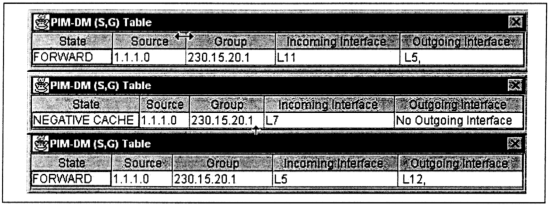


Figure 6.12 Example of GUI PIM-DM (S, G) Table for Router R5, R6 and R7

In the simulation, all events in *PIMDM* have been logged into a file. Besides, GUI table entries are also used as a reference in validating the operation of *PIMDM*. The simulation has been monitored at randomly picked time. The processed results are displayed in Table 6.5. From the results in Table 6.5, the condition of multicast tree establishments is constructed and presented in Figure 6.13, Figure 6.14, Figure 6.15 and Figure 6.16.

Table 6.5 Results for Tree Establishment and Multicast Packets Forwarding Test

Simulation Time (second)	Existing Member	Router	PIM-DM (S, G) Entries for (1.1.1.0, 230.15.20.1)		
			State	Incoming Interface	Outgoing Interfaces
2	None	R1	Negative Cache	L6	No Outgoing Interfaces
		R2	Negative Cache	L2	No Outgoing Interfaces
		R3	Negative Cache	L3	No Outgoing Interfaces
		R4	Negative Cache	L4	No Outgoing Interfaces
		R5	Negative Cache	L11	No Outgoing Interfaces

		R6	Negative Cache	L7	No Outgoing Interfaces
		R7	Negative Cache	L5	No Outgoing Interfaces
		R8	Negative Cache	L8	No Outgoing Interfaces
50	RG1-1	R1	Negative Cache	L6	No Outgoing Interfaces
		R2	Negative Cache	L2	No Outgoing Interfaces
		R3	Negative Cache	L3	No Outgoing Interfaces
		R4	Negative Cache	L4	No Outgoing Interfaces
		R5	Forward	L11	L5
		R6	Negative Cache	L7	No Outgoing Interfaces
		R7	Forward	L5	L12
		R8	Negative Cache	L8	No Outgoing Interfaces
100	RG1-1 RG1-5	R1	Negative Cache	L6	No Outgoing Interfaces
		R2	Negative Cache	L2	No Outgoing Interfaces
		R3	Forward	L3	L16
		R4	Forward	L4	L3
		R5	Forward	L11	L5, L4
		R6	Negative Cache	L7	No Outgoing Interfaces
		R7	Forward	L5	L12
		R8	Negative Cache	L8	No Outgoing Interfaces
160	RG1-1 RG1-5 RG1-2 RG1-3 RG1-4	R1	Forward	L6	L15
		R2	Negative Cache	L2	No Outgoing Interfaces
		R3	Forward	L3	L16
		R4	Forward	L4	L3, L7
		R5	Forward	L11	L5, L4
		R6	Forward	L7	L6, L14
		R7	Forward	L5	L12, L8
		R8	Forward	L8	L13
480	RG1-1 RG1-5 RG1-4	R1	Forward	L6	L15
		R2	Negative Cache	L2	No Outgoing Interfaces
		R3	Forward	L3	L16
		R4	Forward	L4	L3, L7
		R5	Forward	L11	L5, L4
		R6	Forward	L7	L6
		R7	Forward	L5	L12
		R8	Negative Cache	L8	No Outgoing Interfaces
660	None	All Routers	None	None	None

In Figure 6.13, multicast packets are flooded into the networks. Since there is no member exists for the multicast group of 230.15.20.1 at that time, all routers prune the multicast packets that forward to the routers. Packets that come from a not RPF incoming interface are also pruned.

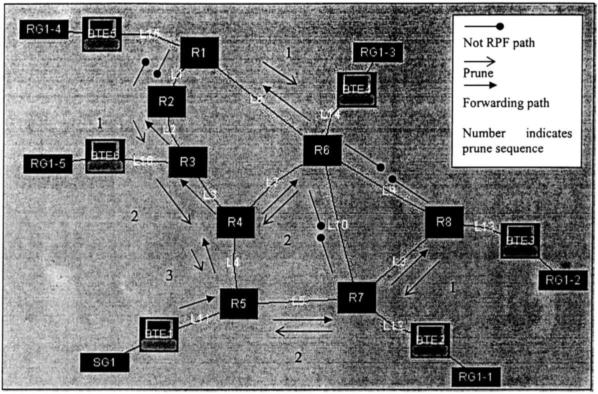


Figure 6.13 Condition of Multicast Packets Forwarding at 2nd Second of Simulation

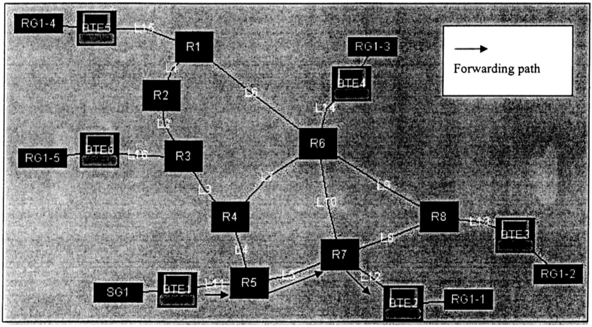


Figure 6.14 Multicast Tree at 50th Second of Simulation

In Figure 6.14, at simulation time of 50 seconds, there is only RG1-1, which is attached to BTE2, joined multicast group 230.15.20.1. Thus, multicast packets are only delivered to BTE2 through R5 and R7. Previously, no member exists, R5 does not forward out any multicast packets. When RG1-1 joins, R7 grafts the forwarding path from R5.

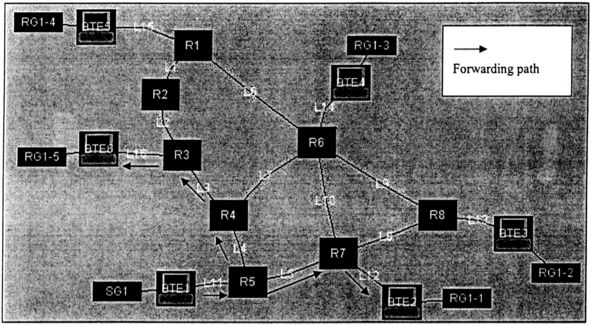


Figure 6.15 Multicast Tree at 100th Second of Simulation

In Figure 6.15, at simulation time of 100 seconds, RG1-5 joins. Similarly, R3 grafts forwarding path from upstream router, R4 and R5. A forwarding path is established towards BTE6 after the grafting.

At 160th seconds, all 5 members join the multicast group 230.15.20.1. Three newly joined members have grafted a forwarding path toward respective BTE. New multicast tree is constructed to deliver multicast packets to the members of the group.

In Figure 6.17, at 480th seconds, two members have left. They are RG1-2 and RG1-3. The outgoing interface at router R8 and R6 toward these two members are pruned and no multicast packets are forwarded to BTE3 and BTE4, which are attached by RG1-2 and RG1-3 respectively.

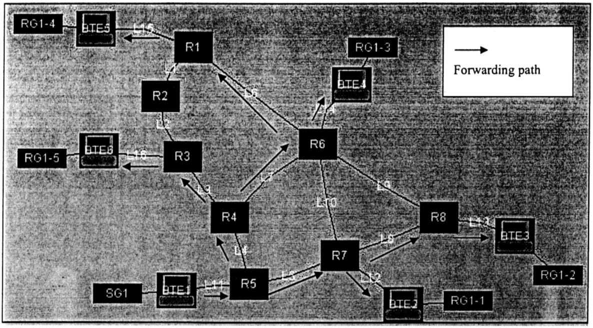


Figure 6.16 Multicast Tree at 160th Second of Simulation

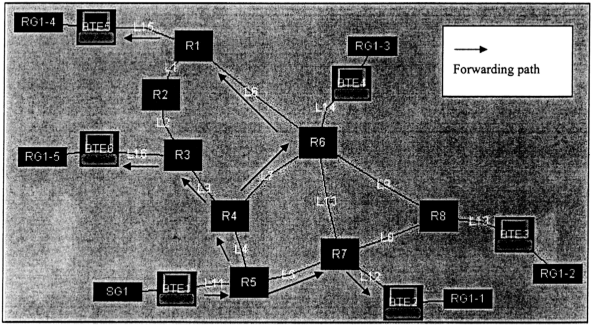


Figure 6.17 Multicast Tree at 480th Second of Simulation

Finally, when there are no more multicast packets sent by the sending source, SG1, the multicast tree is torn down.

Scenario 2: More than One Multicast Group

Testing or Simulation Environment:

- A network topology is created as shown in Figure 6.18.

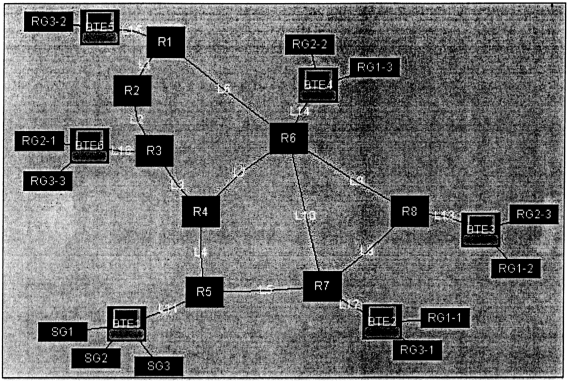


Figure 6.18 Network Simulation Topology for Tree Establishment and Multicast Packets Forwarding Test in Scenario 2

- Input parameters these tests are stated in Table 6.6.
- Simulation time: 660 seconds

Table 6.6 Input Parameters for Scenario 2

Members	RG1-1 to 3	RG2-1 to 3	RG3-1 to 3
Multicast group address	230.15.20.1	235.45.63.2	236.30.12.3
Join time seconds	144	145	143
Duration seconds	360	361	159
Source	SG1	SG2	SG3
Multicast group address	230.15.20.1	235.45.63.2	236.30.12.3
Start time (second)	2	3	2
Data rate (micro second)	51344	51344	51343
Stop time (second)	600	601	600

Result and Analysis

The SG entry condition at simulation time of 180th seconds is recorded. It is shown in Table 6.7.

Table 6.7 Results Recorded at 180 Seconds in Scenario 2

Router	Group	State	Incoming Interface	Outgoing Interfaces
R1	230.15.20.1	Negative Cache	L6	No Outgoing Interfaces
	235.45.63.2	Forward	L6	No Outgoing Interfaces
	236.30.12.3	Forward	L6	L15
R2	230.15.20.1	Negative Cache	L2	No Outgoing Interfaces
	235.45.63.2	Negative Cache	L2	No Outgoing Interfaces
	236.30.12.3	Negative Cache	L2	No Outgoing Interfaces
R3	230.15.20.1	Negative Cache	L3	No Outgoing Interfaces
	235.45.63.2	Forward	L3	L16
	236.30.12.3	Forward	L3	L16
R4	230.15.20.1	Negative Cache	L4	No Outgoing Interfaces
	235.45.63.2	Forward	L4	L3
	236.30.12.3	Forward	L4	L3
R5	230.15.20.1	Forward	L11	L5
	235.45.63.2	Forward	L11	L4, L5
	236.30.12.3	Forward	L11	L4, L5
R6	230.15.20.1	Forward	L10	L14
	235.45.63.2	Forward	L10	L14
	236.30.12.3	Forward	L10	L6
R7	230.15.20.1	Forward	L5	L8, L10, L12
	235.45.63.2	Forward	L5	L8, L10, L12
	236.30.12.3	Forward	L5	L10, L12
R8	230.15.20.1	Forward	L8	L13
	235.45.63.2	Forward	L8	L13
	236.30.12.3	Negative Cache	L8	No Outgoing Interfaces

At 180th seconds, all members join respective multicast group. The established multicast tree for a particular multicast group is shown in Figure 6.19. From the analysis, it is found that, in multiple group situations, the PIMDM still could handle multicast tree and forward multicast packet to the correct destinations.

Conclusions:

From the above tests, both scenario 1 and scenario 2, it is found that *PIMDM* could establish multicast tree correctly and forward out multicast packet to the correct destination. Indirectly, it means, *PIMDM* can handle PIM-DM message, timers, membership entries, neighbor and forwarding correctly.

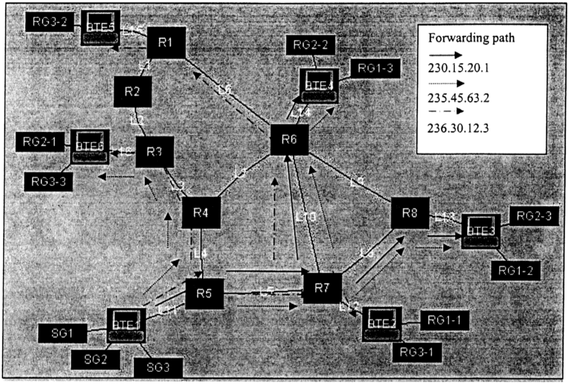


Figure 6.19 Multicast Tree Established for Three Different Multicast Group

6.3 Performance Evaluation on IP Multicast Through PIM-DM

The purpose of this section is to evaluate and analyze the performance of IP Multicast using PIM-DM in different membership distribution pattern.

Basically, two types of multicast group membership distribution pattern are employed here. The first type is dense distribution, where the multicast group membership is spread almost everywhere over the network topology. The second type is sparse distribution, in which the multicast group membership is located at certain areas in the entire network.

Several aspects can be used to evaluate the performance of a multicast routing protocol in IP multicasting [22, 51]. Some of the criteria are stated below.

- Join Latency
- Leave Latency
- Link Utilization and Traffic Concentration
- Data Distribution Overhead
- Protocol Overheads
- Size of Routing Table
- End-to-end delay of delivery
- Scaling
- Complexity of Implementation
- Convergence Time

Among the above performance criteria, join latency, traffic concentration, and protocol overhead are used as the parameters of evaluation. Table 6.8 explains the performance parameters used in the evaluation test.

Table 6.8 Performance Parameters for Evaluating Multicast Routing Protocol [22]

Performance parameter	Description
Join Latency	The time taken to receive first multicast packet from the multicast group after joining that multicast group
Traffic Concentration	A measure of the distribution of the total network utilization on all links defined to be the ration of the maximum utilization carried by any link to the average utilization of all links
Protocol Overhead	The overhead created by multicast routing protocol in order to establish and maintain multicast distribution trees.

To determine these three performance parameters, modification and method of calculation are defined. It is stated as below.

- **Join Latency**

  In the test, average of join latency is determined. A low latency is preferred.

Join latency = {(time received first packet) – (time started joining a multicast group)}

Average join latency = Sum of join latency / total members

The IGMP timer, the sending rate of data and the size of the topology may affect the join latency. However, since the simulation tests are performed in the same environment, these factors can be eliminated.

- **Traffic Concentration**

  Two measurements can be taken on the link utilization. The first measurement is average link utilization for the links in entire network. The second measurement is the traffic concentration parameters, which is equal to the ratio of the maximum link utilization in the network to the average link utilization of all links in the network. [51]

  Traffic concentration index = (the maximum link utilization) / (average links Utilization)

- **Protocol Overhead**

  In the study, protocol overhead is determined by the average number of PIM-DM control messages exchanged during the simulation in a link. Since the number of routers and simulation time in each simulation are the same, protocol overhead index is defined as below.

  Protocol overhead index = (total number of messages) / (number of links)

Several simulation tests have been carried out and results are recorded, processed and presented in a graph or table format. Absolute values of the results collected are not important in these tests. In fact, the relationship and results pattern are concerned.

The topology used in the simulations is modified from a local ISP network topology. This topology could provide a simulation test that is near to a real environment. During the simulation, each network topology is static and there is no lost of packets.

During the simulation test, four sets of test have been done on dense distribution and sparse distribution respectively. Each set of test involves different number of membership. There are 10, 15, 20 and 25 of members respectively. The distributions of the multicast member in both dense distribution and sparse distribution are randomly allocated. The test topologies are shown in Figures below.

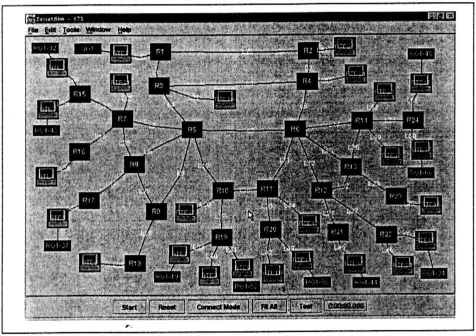


Figure 6.20 Topology for10 Members Dense Distributions

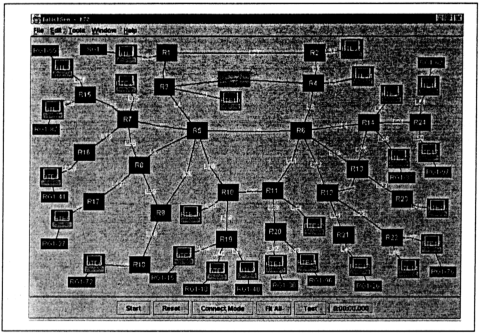


Figure 6.21 Topology for 15 Members Dense Distributions

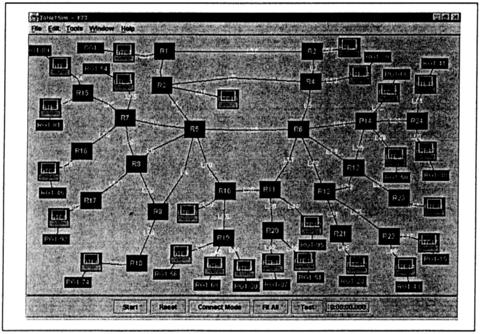


Figure 6.22 Topology for 20 Members Dense Distributions

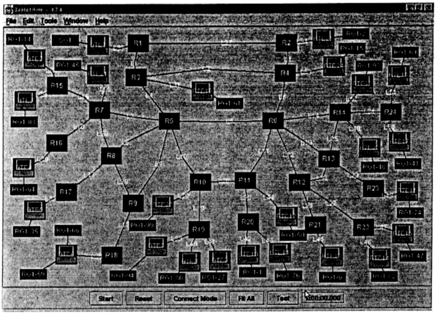


Figure 6.23 Topology for 25 Members Dense Distributions

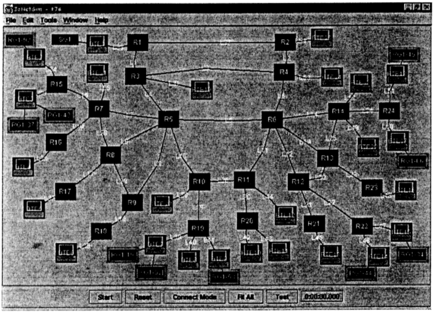


Figure 6.24 Topology for 10 Members Sparse Distributions

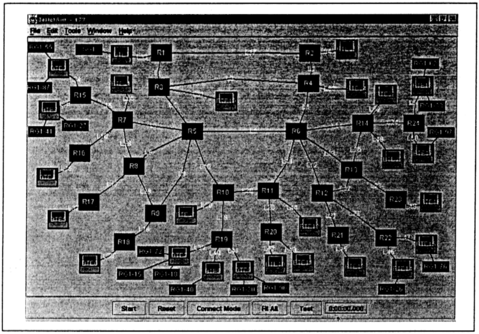


Figure 6.25 Topology for 15 Members Sparse Distributions

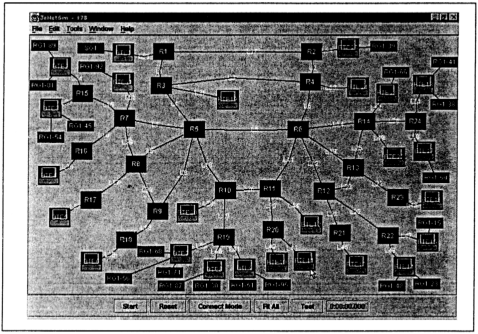


Figure 6.26 Topology for 20 Members Sparse Distributions

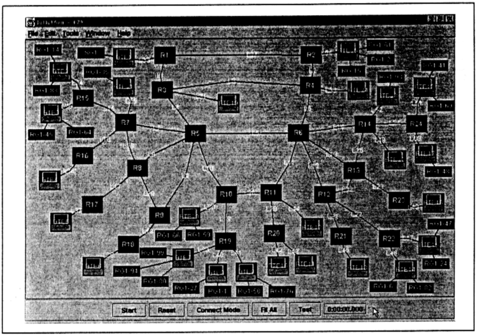


Figure 6.27 Topology for 25 Members Sparse Distributions

In the tests, a one-to-many application is simulated. It assumes that the multicast application involved in the test is an online news application. This service is available all the time. Users who are interested in viewing the online news may issue a join event to this multicast group. For the simulation test, it also assumes that the application send data at a constant rate of 256 kbps and an average of 30 minutes has been spent for each member each time. The simulation is carried out for 45 minutes in simulation time. During the simulation, a host may join and leave at random time for average of 30 minutes in simulation time.

A simulation for 45 minutes may take longer than 7 hours. Hence, scaling down the simulation time and data rate is done in order to reduce the time taken for a simulation. In fact, scaling down the simulation time and data rate is only shortening the events occurrence time. The entire events that occur in 45 minutes of simulation time will happen in a shorter duration. Furthermore, the concentration is not focused on the absolute value of the results, so it does not affect the results. A scale factor of 0.2 and 0.032 are chosen respectively for simulation time and data rate.

To ensure a fairness in the simulation for both distribution patterns, the simulation application for multicast members are assigned a similar set of names, so that the join and leave event in both simulation are the same. (Refer to section 5.3.2) The number of links, routers, and BTEs are constant. The only difference is the distribution pattern and number of members.

6.3.1 Join Latency Test

Objective:

- To determine and analyze join latency in dense distribution and sparse distribution with various number of members involved

Testing or Simulation Environment:

- Four different numbers of members in two different distribution patterns are tested. The number of members involved in the test was 10, 15, 20, and 25 respectively. Figure 6.20 to Figure 6.27 show the topologies for these tests.
- Input parameter used for *IPMulticastApp* application.
  -Multicast group address : 230.15.20.1
  -Join time : 100 seconds
  -Duration : 360 seconds
- Input parameter used for *MulticastdataApp* application.
  -Multicast group address : 230.15.20.1
  -Start time : 2 seconds
  -Data rate : 51344 microseconds
  -Stop time : 600seconds
- Simulation time : 600 seconds

Results and Analysis:

From Figure 6.28, it is found that when number of members increase, the join latency decreases. This is because when the number of members increases, the possibility of members joining in a members existing area is higher. Since multicast tree is already established towards the area, the join latency decreases indirectly. The reason is the new members do not need to spend time for grafting branches in the distribution tree.

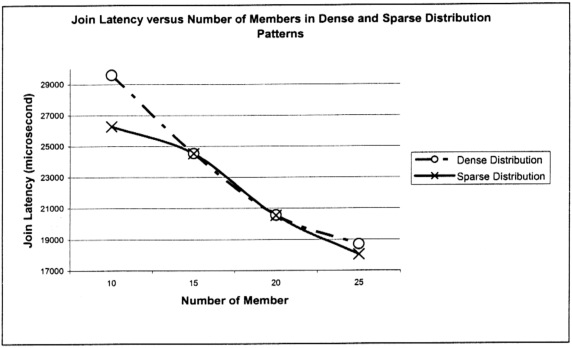


Figure 6.28 Join Latency versus Number of Members in Dense Distribution and Sparse Distribution

When comparing join latency for two different distribution patterns, it is found that sparse distribution pattern has lower join latency than the dense distribution pattern. In sparse distribution, the possibility of members joining in a members existing area is higher than dense distribution. The existing distribution tree in sparse distribution allows new members to receive multicast packet faster. However, in dense distribution, low density of members exists in an area. This may require a new member in certain areas to send a graft towards the multicast sending source. Therefore, delay of receiving multicast packets may cause the increasing of the latency.

Conclusions:

Different distribution patterns may affect join latency for a multicast member. For PIM-DM, the join latency for sparsely distributed multicast members is lower than the densely distributed pattern in the simulation test.

6.3.2 Traffic Concentration Test

Objective:

- To determine and analyze traffic concentration for IP multicast in dense distribution and sparse distribution, involving various number of members

Testing or Simulation Environment:

- The simulation environment for this test is same as section 6.3.1.

Results and Analysis:

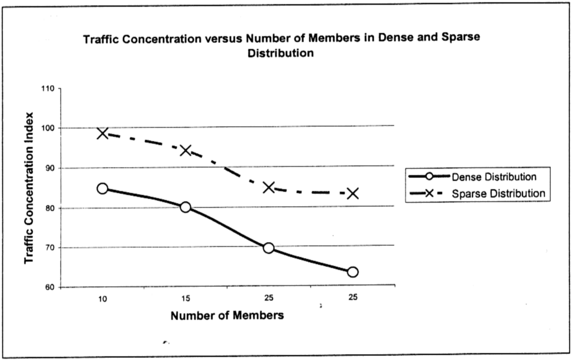


Figure 6.29 Traffic Concentrations versus Number of Members in Dense Distribution and Sparse Distribution

From Figure 6.29, it is found that the traffic concentration for dense distribution and sparse distribution is decreased when the number of members is increased. In the simulation tests of both dense distribution and sparse distribution, when number of members increased, the members are distributed in more areas in the network.

Multicast traffic is delivered to the members by using several sets of delivery paths. Hence, the traffic concentration is decreased.

When comparing 2 different distribution patterns, it is found that the traffic concentration for sparse distribution is generally higher than dense distribution. Since members are densely distributed over the topology in dense distribution test, number of paths utilized for delivery is greater than number of paths used in sparse distribution. Thus, densely distributed pattern has lower traffic concentration.

Conclusions:

Distribution pattern for multicast members could affect the traffic concentration in a network. Dense distribution pattern has lower traffic concentration than sparse distribution pattern in the simulation test.

6.3.3 Protocol Overhead Test

Objective:

- To determine and analyze protocol overhead for IP multicast in dense distribution and sparse distribution, involving various number of members.

Testing or Simulation Environment:

- The simulation environment for this test is same as section 6.3.1.

Results and Analysis:

From Figure 6.30, it is found that the protocol overhead index in densely distributed pattern is smaller than sparsely distributed pattern.

In dense distribution of multicast membership, multicast group members exist at almost every area in the network. In the simulation tests, the average number of pruned interfaces in dense distribution is generally smaller than the average number of pruned interface in sparse distribution. When prune timer expired, PIM-DM performed broadcast forwarding, allowing the multicast traffic to flow through the previously pruned interfaces. Prune message is sent back towards the source if there is no members exist at the downstream. The number of prune messages generated in sparse distribution is slightly higher. This is because of the possibility of no members exist in an area in sparse distribution pattern is higher. Therefore, protocol overhead index in sparse distribution pattern is found higher than in dense distribution.

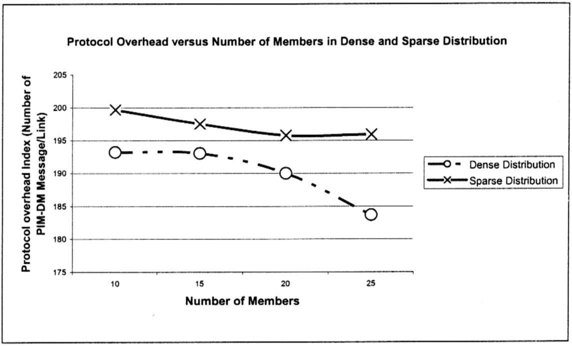


Figure 6.30 Protocol Overhead versus Number of Members in Dense Distribution and Sparse Distribution

Conclusions:

Multicast membership distribution pattern has an impact on the protocol overhead. In this simulation test, dense distribution pattern has a smaller protocol overhead index than the sparse distribution pattern.

6.4 Summary

This chapter covers the validation test for the implementation of component and performance test for IP Multicast using PIM-DM through simulation. The validation test is carried out in order to verify the correctness in implementation. The performance test is done in order to evaluate the performance of IP Multicast using PIM-DM in two different membership distribution patterns. There are dense distribution and sparse distribution. The evaluation concentrates on join latency, traffic concentration and protocol overhead. Objectives, simulation environment, results and analysis as well as conclusion for each test are presented in this chapter. The next chapter is the conclusion of this dissertation.