Chapter 8

Performance Evaluation of the Proposed nearest PIM-SM Extension for Anycast Routing

8.1 Simulations Results

With the simulation environment that has been created, several scenarios are simulated to observe the performance of each anycast routing protocol and the effects of the load-balancing scheme applied.

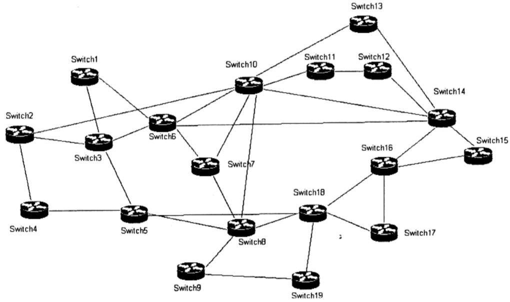

Figure 8.1 *MCI topology*

A topology based on the MCI Internet backbone (shown in Figure 8.1) is used as it represents a typical large ISP topology. The topology contains 19 routers and 32 links. The bandwidths are scaled down from their actual values in order to reduce the volume of the simulations. The resulting bandwidths are 3 Mbps and the cost for each link is 1.

Each router is connected to a customer site (IPv6 B-TE) representing an aggregate of traffic. Variable Bit Rate (VBR) is used as the traffic model in the simulations. The characteristics of the VBR traffic source are shown in Table 8.1.

The anycast group service providers are connected to a customer site as well. The characteristics of the service providers are listed in Table 8.2.

Table 8.1 VBR source characteristics

Characteristic	**Value**
Bit Rate (MBits/s)	1.0
Mean Burst Length (μsecs)	5000.0
Mean Interval Between Bursts (μsecs)	15000.0
Start Time (secs)	70
Number of MBits to be sent	2.0
Repeat count (-1=infinite)	4
Delay between calls (μsecs)	3000000
Destination IPv6	3e00:0000:0000:0000:fdff:ffff:ffff:fffe

Table 8.2 Anycast service provider's source characteristics

Parameter	**Value**
Group Address To Join	3e00:0000:0000:0000:fdff:ffff:ffff:fffe
Join Group Time (secs)	50
Leave Group Time (secs) (-1=infinite)	-1

For each of the anycast routing and load-balancing scheme, multiple simulation sessions are performed, each with increasing traffic load. The traffic load ranges from light to heavy, to observe the capability of each scheme to load balance the traffic. The random number generator for each simulation session uses the same seed to ensure fairness among each scheme. The smallest time unit is one tick (10 nanoseconds) and the simulation sessions are run for 120 seconds ($1.2 * 10^{10}$ ticks).

The simulation sessions involved the schemes listed in Table 8.3. The "mode" simply denoted that the scheme is purely single-path approaches, purely multi-path approaches or with both single-path and multi-path approaches.

Table 8.3 Anycast routing schemes and its mode

Schemes	Single-path	Multi-path	Mode
RIPng extension	X		Pure
PIM-SM extension with shortest-path	X		Pure
PIM-SM extension with round robin		X	Pure
PIM-SM extension with fuzzy shortest-path	X	X	Mixed
Nearest PIM-SM extension with shortest-path	X		Pure
Nearest PIM-SM extension with round robin		X	Pure
Nearest PIM-SM extension with fuzzy shortest-path	X	X	Mixed
Nearest PIM-SM extension with mixed load-balancing	X	X	Mixed

For nearest PIM-SM mixed load-balancing scheme, several routers are selected to implement round robin scheme, while the rest are implementing fuzzy shortest-path scheme. A router is selected to implement round robin scheme if it has more than *k* links connected to it. The more links a router attached by, the higher possibility that an alternative route is selected. Router selection based on the number of links is preferred compare to the selection based on the traffic load (Wei Jia et al., 2000a) as it is simpler and easier to implement. Furthermore, the latter selection method requires more overhead and knowledge about the traffic in the whole network to perform the router selection process, which is not very feasible for a large topology. Besides, the router selected in the latter router selection method is not able to perform load distribution if it only has one route towards the anycast service provider (heavily loaded router but has only available route).

For round robin, where k = number of links

$$\text{Probability of selecting a route} \propto \frac{1}{k}$$

$$\text{Probability of selecting an alternative route} \propto \frac{1}{\text{Probability of selecting a route}}$$

thus,

$$\text{Probability of selecting an alternative route} \propto k$$

The distribution of traffic sources and anycast service providers has great impact on the results of the simulation sessions. This thesis uses five types of randomly generated traffic sources-service provider distributions, each based on the MCI Internet backbone topology for a thorough study on the anycast routing. The traffic sources-service providers distributions used are:

a) Topology A (Figure 8.2)

b) Topology B (Figure 8.3)

c) Topology C (Figure 8.4)

d) Topology D (Figure 8.5)

e) Topology E (Figure 8.6).

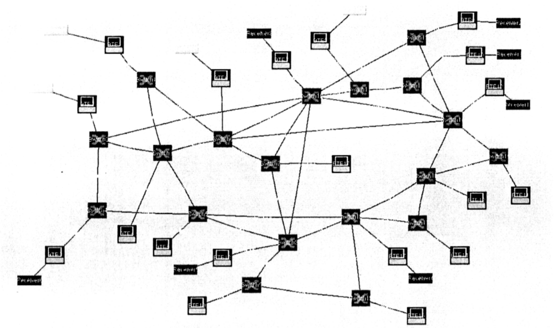

Figure 8.2 *Topology A*

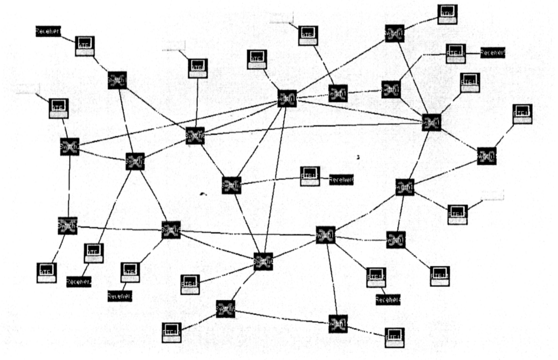

Figure 8.3 *Topology B*

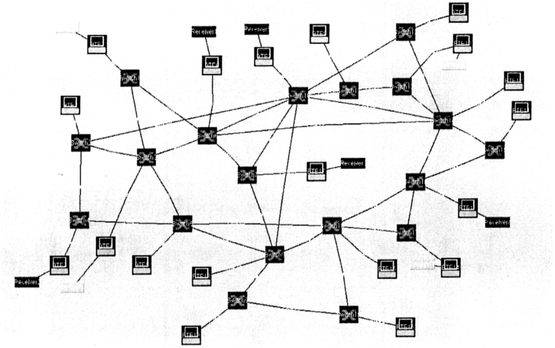

Figure 8.4 *Topology C*

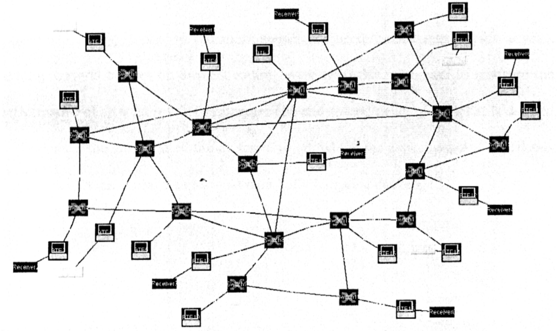

Figure 8.5 *Topology D*

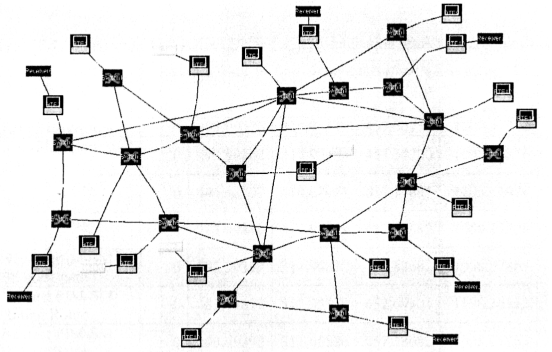

Figure 8.6 *Topology E*

8.1.1 End-To-End Delay

End-to-end Delay is one of the most significant performance metrics for anycast routing. Several studies on anycast routing were used this parameter to measure the performance of anycast routing protocols. The end-to-end delay of a packet is defined as the sum of the delays at all the routers through which the packet passes. This thesis is interested in the average end-to-end delay of all anycast packets.

Topology A

Table 8.4 Average End-to-End Delay for each simulation sessions in Topology A

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	293.99526	317.94423	457.36756	1007.97002
PIM-SM Shortest-path	0	293.99862	317.95498	457.34700	1008.15276
PIM-SM Round Robin	0	444.18307	470.67057	617.77645	1203.01079
PIM-SM Fuzzy Shortest-path	0	293.99840	317.95498	457.38682	1008.15276
Nearest PIM-SM Shortest-path	0	293.99392	317.96820	455.88682	1008.07865
Nearest PIM-SM Round Robin	0	483.74877	511.35970	652.69801	1198.36132
Nearest PIM-SM Fuzzy Shortest-path	0	293.99392	317.96820	457.38682	1008.07865
Nearest PIM-SM Mixed	0	379.53438	404.52748	543.94767	1095.06665

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	**24**	**28**	**32**
RIPng extension	3849.08197	27006.40954	30730.41088	32552.35290
PIM-SM Shortest-path	3950.28520	27003.82278	30730.27035	32554.22141
PIM-SM Round Robin	4226.32587	27541.82214	32245.40459	48205.52946
PIM-SM Fuzzy Shortest-path	3950.28565	27004.06460	30730.27035	35552.89331
Nearest PIM-SM Shortest-path	3949.34429	27006.92730	30731.00983	32552.89331
Nearest PIM-SM Round Robin	4121.26418	27132.04527	30783.36510	32435.25301
Nearest PIM-SM Fuzzy Shortest-path	3949.34429	27006.92730	30731.00983	32552.89331
Nearest PIM-SM Mixed	4038.51377	27092.37837	30563.08608	32641.89187

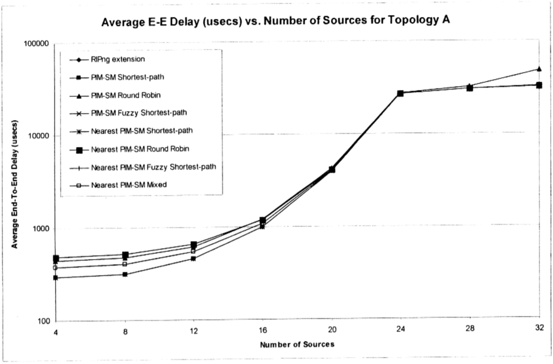

Figure 8.7 *Average End-to-End Delay vs. Number of Sources for Topology A*

The performances of the schemes using single-path approaches (RIPng extension, PIM-SM shortest-path, PIM-SM fuzzy shortest-path, nearest PIM-SM shortest-path, nearest PIM-SM fuzzy shortest-path, except nearest PIM-SM mixed) in Topology A fare better than the schemes using purely multi-path approaches (PIM-SM round robin, nearest PIM-SM round robin). The nearest PIM-SM extension with mixed load-balancing schemes using both single-path and multi-path approaches performs better than the schemes using purely multi-path approaches, but poorer than the schemes using single-path approaches (except nearest PIM-SM mixed).

From Figure 8.7, schemes using single-path approaches (except nearest PIM-SM mixed) have lower average end-to-end delay than the schemes using purely multi-path approaches and the nearest PIM-SM extension with mixed load-balancing scheme when the traffic load is light or moderate (< 20 sources). However, the average end-to-end delay for the schemes using single-path approaches (except nearest PIM-SM mixed) increase at a higher rate in this same range. The average end-to-end delay for all the schemes increase at a similar rate when traffic load is heavy (from 20 to 24 sources). However, when traffic load is very heavy (> 24 sources), the average end-to-end delay for the schemes using single-path approaches (except nearest PIM-SM mixed) increase a slower rate and is lower than the schemes using purely multi-path approaches and the nearest PIM-SM extension with mixed load-balancing scheme.

This observation shows the failure of the schemes using purely multi-path schemes to load balance traffic. This sharply contrasts with the results presented by Dong Xuan et al. (2000), which claims that the schemes that using multi-path approaches would perform better than the schemes using single-path approaches when traffic load becomes heavier.

Topology B

Table 8.5 Average End-to-End Delay for each simulation sessions in Topology B

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	246.75505	255.37556	266.22095	298.67231
PIM-SM Shortest-path	0	505.60316	540.07812	683.78148	1226.44497
PIM-SM Round Robin	0	576.73621	608.90790	761.47586	1363.55216
PIM-SM Fuzzy Shortest-path	0	505.60316	540.07812	683.78148	1226.44497
Nearest PIM-SM Shortest-path	0	246.75842	255.38380	266.22954	298.68021
Nearest PIM-SM Round Robin	0	431.07318	439.83728	449.58017	470.78660
Nearest PIM-SM Fuzzy Shortest-path	0	246.75842	255.38380	266.22954	298.67993
Nearest PIM-SM Mixed	0	263.54301	271.03641	281.79391	312.54171

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	**24**	**28**	**32**
RIPng extension	386.05716	560.80316	930.32694	1640.46706
PIM-SM Shortest-path	5579.30651	28035.97156	31819.23508	34201.70121
PIM-SM Round Robin	5932.55216	29204.51069	39632.80895	54610.45819
PIM-SM Fuzzy Shortest-path	5579.30651	28035.65207	31819.23509	34295.45121
Nearest PIM-SM Shortest-path	386.06992	560.83750	930.72136	1640.70125
Nearest PIM-SM Round Robin	526.23041	637.13865	835.76477	1222.65199
Nearest PIM-SM Fuzzy Shortest-path	386.06992	560.83750	930.72200	1640.64981
Nearest PIM-SM Mixed	395.16505	564.10014	943.11599	1775.82909

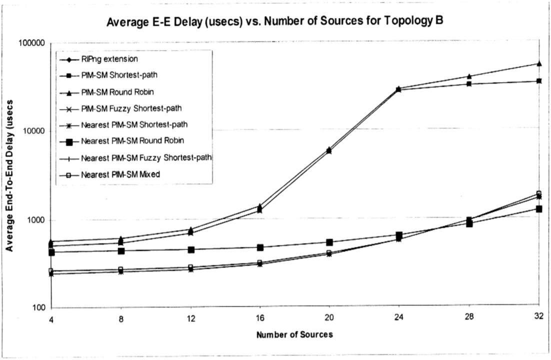

Figure 8.8 *Average End-to-End Delay vs. Number of Sources for Topology B*

A typical core-based tree faces the problems of traffic concentrating around the Rendezvous Point (RP) and "hot-spot" (refer to Section 6.3). As a result, the PIM-SM extension also faces the same problems. These problems are exposed in the simulation results for Topology B.

The simulation results show that RIPng extension and nearest PIM-SM schemes perform far better than PIM-SM extension in Topology B as the average end-to-end delay for the PIM-SM schemes are always higher than the other schemes in all traffic conditions.

The average end-to-end delay for the PIM-SM extension either with shortest-path, round robin or fuzzy shortest-path increases very quickly when the traffic load is heavy (from 16 to 24 sources). The sudden increase of the end-to-end delay by the

PIM-SM extension is caused by the worsening condition of the traffic and the failure of the PIM-SM extension schemes to distribute the traffic load. The end-to-end delay increases slowly when the traffic load is very high. However packet loss is not taken into account when calculating the average end-to-end delay. Usually packet loss results in an infinite end-to-end delay, but this is not done to observe greater differentiation between the protocol performances.

The nearest PIM-SM extension scheme uses a single-path approach for off-tree hits (refer to Section 6.2). As a result, the nearest PIM-SM extension scheme outperforms the PIM-SM extension in all the simulations.

The nearest PIM-SM extension scheme using single-path approach performs better than the nearest PIM-SM extension scheme using multi-path approach when the traffic load is not that heavy (<28 sources). However, the nearest PIM-SM extension scheme using multi-path approach performs better when the traffic load is very high (28 to 32 sources). The capability of the multi-path approach to distribute the traffic load more evenly helps in reducing the average end-to-end delay.

Topology C

Table 8.6 Average End-to-End Delay for each simulation sessions in Topology C

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	292.67047	305.71450	348.39284	548.32984
PIM-SM Shortest-path	0	292.67047	305.71450	348.39284	548.32984
PIM-SM Round Robin	0	367.30133	.376.53762	388.59328	423.42627
PIM-SM Fuzzy Shortest-path	0	292.67047	305.71450	348.39284	548.32984
Nearest PIM-SM Shortest-path	0	292.67271	305.71507	348.39210	548.30803
Nearest PIM-SM Round Robin	0	510.32197	524.42194	540.12806	577.53843
Nearest PIM-SM Fuzzy Shortest-path	0	292.67271	305.71282	348.39180	548.30517
Nearest PIM-SM Mixed	0	441.45195	449.96320	461.12139	494.11859

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**			
	20	**24**	**28**	**32**
RIPng extension	1606.12051	37571.17141	399466.04649	807390.75191
PIM-SM Shortest-path	1606.12051	37571.17141	399466.04649	807390.75191
PIM-SM Round Robin	510.57225	701.30331	1105.97420	1934.81111
PIM-SM Fuzzy Shortest-path	1606.12051	37571.17133	399466.04649	1024510.20358
Nearest PIM-SM Shortest-path	1606.11317	37571.16466	399466.04533	807390.75598
Nearest PIM-SM Round Robin	664.72156	923.79169	1224.46866	2096.92061
Nearest PIM-SM Fuzzy Shortest-path	1606.11550	37571.16466	399466.04531	807390.75534
Nearest PIM-SM Mixed	589.66314	770.92103	1125.65570	2096.86502

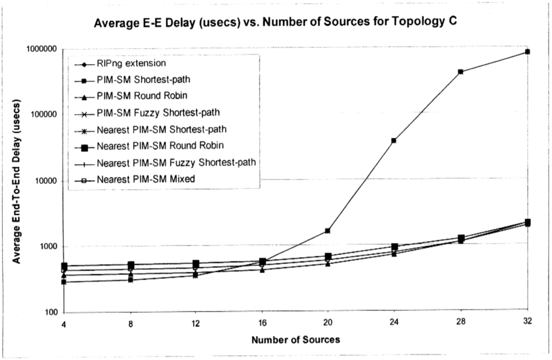

Figure 8.9 *Average End-to-End Delay vs. Number of Sources for Topology C*

The failure of the single-path approach to distribute the traffic load properly is exposed in the simulation results for Topology C. In contrast, the schemes using multi-path approaches that can distribute the traffic better are performing well.

The schemes using single-path approaches (nearest PIM-SM mixed) perform better than the schemes using multi-path approaches (including the nearest PIM-SM extension with load-balancing scheme) when the traffic load is light or moderate (<16 sources). However, the schemes using single-path approaches (nearest PIM-SM mixed) are outperformed when the traffic load is heavier (>12 sources). The average end-to-end delay for the schemes using single-path approaches (nearest PIM-SM mixed) increase at a very high rate when the traffic load is heavy (20 to 28 sources). The average end-to-end delay increases slower when the traffic load is very heavy (28 to 32 sources).

Schemes using multi-path approaches perform better than the schemes using single-path approaches (nearest PIM-SM mixed) when the traffic load is quite heavy (> 16 sources). The average end-to-end delay of these schemes only increases gradually when the traffic load increases, as the traffic can be more properly distributed.

The nearest PIM-SM extension with mixed load-balancing scheme that has both the characteristics of the single-path approach (nearest PIM-SM mixed) and multi-path approach performs similarly to the schemes using purely multi-path approaches in these simulations. This scheme performs better than the schemes using purely multi-path approaches but poorer than the schemes using single-path approaches (nearest PIM-SM mixed) when the traffic load is light or moderate (<16 sources). When the traffic load is quite heavy (>16 sources), the average end-to-end delay for this scheme increases at a rate similar to the schemes using purely multi-path. Generally this scheme always performs better than the nearest PIM-SM extension with round robin but poorer than the PIM-SM extension with round robin.

Topology D

Table 8.7 Average End-to-End Delay for each simulation sessions in Topology D

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	247.83036	257.54746	269.93857	307.59358
PIM-SM Shortest-path	0	247.82992	257.54959	269.94051	307.62480
PIM-SM Round Robin	0	331.56496	340.18914	351.24673	384.29819
PIM-SM Fuzzy Shortest-path	0	247.82992	257.54959	269.94051	307.62458
Nearest PIM-SM Shortest-path	0	247.83014	257.54735	269.93827	307.59352
Nearest PIM-SM Round Robin	0	526.79263	535.28105	543.87680	568.30089
Nearest PIM-SM Fuzzy Shortest-path	0	247.83014	257.54735	269.93827	307.59375
Nearest PIM-SM Mixed	0	350.08381	359.98509	373.81141	415.06022

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**			
	20	**24**	**28**	**32**
RIPng extension	406.94721	634.38011	1143.09332	2432.60118
PIM-SM Shortest-path	406.96746	634.32602	1143.01621	2432.63688
PIM-SM Round Robin	466.89487	646.37420	1012.70528	1669.52612
PIM-SM Fuzzy Shortest-path	407.86745	634.32590	1143.01728	2432.66188
Nearest PIM-SM Shortest-path	406.95012	634.40541	1143.08569	2432.64413
Nearest PIM-SM Round Robin	628.99273	763.07676	1020.73159	1525.55429
Nearest PIM-SM Fuzzy Shortest-path	406.95013	634.39148	1143.08572	2432.65206
Nearest PIM-SM Mixed	518.82064	751.73645	1254.47522	2421.36547

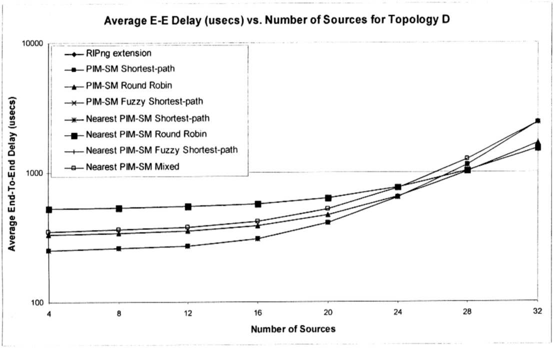

Figure 8.10 *Average End-to-End Delay vs. Number of Sources for Topology D*

Schemes using single-path approaches (nearest PIM-SM mixed) perform better than the schemes using multi-path approaches. However, the average end-to-end delay for these schemes increase at a faster rate as compared to the schemes using multi-path approaches when the traffic is quite heavy (>16 sources).

Schemes using purely multi-path approaches perform poorly when the traffic load is not that heavy (<24 sources). However, when the traffic load is very heavy (>24 sources), the schemes using purely multi-path approaches outperform the schemes using single-path approaches (nearest PIM-SM mixed).

The nearest PIM-SM extension with mixed load-balancing scheme is outperformed by the other schemes (except nearest PIM-SM extension with round robin) when the traffic load is not so heavy (< 24 sources). However, this scheme performs better than the schemes using single-path approaches (except nearest PIM-SM mixed) when the traffic load is very heavy (> 28 sources).

Although the nearest PIM-SM extension with round robin performs poorer than the PIM-SM extension with round robin when the traffic load is not so heavy (<24 source), it performs better than the PIM-SM extension with round robin when the traffic load is very heavy (> 28 sources).

Topology E

Table 8.8 Average End-to-End Delay for each simulation sessions in Topology E

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	47.28221	102.12505	208.56523	588.93113
PIM-SM Shortest-path	0	70.25207	196.10643	1073.35043	20500.78801
PIM-SM Round Robin	0	96.90645	247.30368	1157.32547	20652.81475
PIM-SM Fuzzy Shortest-path	0	70.25207	196.10643	1073.35043	20500.78801
Nearest PIM-SM Shortest-path	0	79.08659	168.05313	313.18207	737.59111
Nearest PIM-SM Round Robin	0	92.83905	193.45545	306.72348	461.11153
Nearest PIM-SM Fuzzy Shortest-path	0	47.28263	102.14131	208.61441	588.99553
Nearest PIM-SM Mixed	0	71.74566	154.18825	344.72274	694.66218

Scheme	**Average End-to-End Delay (μsecs) with *k* number of sources**			
	20	**24**	**28**	**32**
RIPng extension	3106.12197	20087.45351	30526.21640	33355.94143
PIM-SM Shortest-path	29429.79722	49625.18748	423043.50059	829040.24432
PIM-SM Round Robin	29804.38942	51070.92790	434969.32043	853674.76138
PIM-SM Fuzzy Shortest-path	29429.79713	49628.91333	423053.83014	829041.09484
Nearest PIM-SM Shortest-path	3297.91514	20364.08039	30881.60264	421946.32594
Nearest PIM-SM Round Robin	789.85520	2255.88365	23232.76260	38244.22022
Nearest PIM-SM Fuzzy Shortest-path	3104.32825	20088.50924	30526.98565	33357.26984
Nearest PIM-SM Mixed	7441.79507	19781.47455	37053.50870	47730.16974

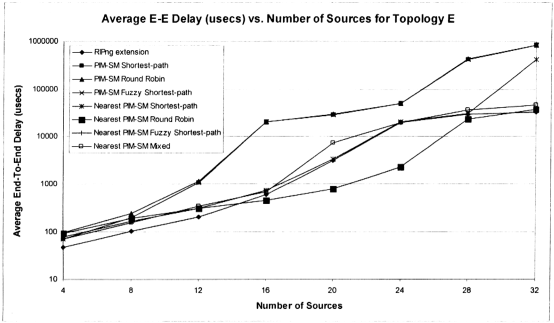

Figure 8.11 *Average End-to-End Delay vs. Number of Sources for Topology E*

The problems of traffic concentrating around the RP and "hot-spot" once again cause the PIM-SM extension to perform poorly. The average end-to-end delay for the PIM-SM extension increases quickly when the traffic load increases from light to moderate (8 to 16 sources). The average end-to-end delay increases slowly when the traffic load is heavy (16 to 24 sources). However, the average end-to-end delay for the PIM-SM extension increases quickly when the traffic load increases from heavy to very heavy (24 to 28 sources).

The nearest PIM-SM extension generally performs better than the PIM-SM extension and its average end-to-end delay increases slowly when the traffic load increases, except the nearest PIM-SM extension with shortest-path when the traffic load is very heavy (28 to 32 sources). The average end-to-end delay for the nearest PIM-SM extension with shortest-path increases suddenly when the traffic load is very heavy (28 to 32 sources) due to the failure of the scheme to choose an alternate route when the shortest-path is congested. The nearest PIM-SM extension with fuzzy shortest-path which uses the shortest-path method but has the ability to choose an alternate route when congestion happens fares better than the nearest PIM-SM extension with shortest-path in this situation. The PIM-SM extension with mixed load-balancing scheme performs fairly in between the PIM-SM extension and the other schemes.

The nearest PIM-SM extension with round robin performs better than the other schemes when the traffic load is higher than moderate (>12 sources). Generally the average end-to-end delay for this scheme increases slowly when the traffic increases, except when the traffic load increases from heavy to very heavy (28 to 32 sources). The average end-to-end delay for all the schemes is moderate when traffic is low (for 4-12 sources, see Figure 8.11), with single-path routing performing better than multi-path routing. The average end-to-end delay for this scheme is higher than the RIPng extension and the nearest PIM-SM extension with fuzzy shortest-path when the traffic load is extremely heavy (32 sources) as the packets loss did not come take into account when calculating the average end-to-end delay. However, the packet loss percentage is the lowest among all the schemes (will be discussed in next section).

8.1.2 Packet Loss Percentage

Packet loss percentage is defined as follows:

$$Packet\ Loss\ Percentage = \frac{Total\ Packets\ Sent - TotalReceivedPackets}{Total\ Packets\ Sent} \times 100\%$$

Low packet loss percentage depicted that less packets are loss during the transmission, thus more reliable.

The discussion of the packet loss percentage will only cover the simulation sessions for Topology A, Topology B and Topology E as there is no packet loss in the simulation sessions for Topology C and Topology D.

Topology A

Table 8.9 Packet loss percentage (%) for each simulation sessions in Topology A

Scheme	Packet loss percentage (%) with *k* number of sources								
	0	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**
RIPng extension	0	0	0	0	0	0	3.81341	9.53722	13.70696
PIM-SM Shortest-path	0	0	0	0	0	0	3.81319	9.53741	13.70729
PIM-SM Round Robin	0	0	0	0	0	0	3.81363	9.53741	14.47958
PIM-SM Fuzzy Shortest-path	0	0	0	0	0	0	3.81363	9.53759	13.70729
Nearest PIM-SM Shortest-path	0	0	0	0	0	0	3.81385	9.53759	13.70729
Nearest PIM-SM Round Robin	0	0	0	0	0	0	3.81341	9.53759	13.70746
Nearest PIM-SM Fuzzy Shortest-path	0	0	0	0	0	0	3.81385	9.53759	13.70729
Nearest PIM-SM Mixed	0	0	0	0	0	0	3.81385	9.53759	13.70746

Topology B

Table 8.10 Packet loss percentage (%) for each simulation sessions in Topology B

Scheme	**Packet loss percentage (%) with *k* number of sources**								
	0	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**
RIPng extension	0	0	0	0	0	0	0	0	0
PIM-SM Shortest-path	0	0	0	0	0	0	4.37523	10.10091	39.53369
PIM-SM Round Robin	0	0	0	0	0	0	4.37523	10.21893	16.38008
PIM-SM Fuzzy Shortest-path	0	0	0	0	0	0	4.37589	10.10091	14.52534
Nearest PIM-SM Shortest-path	0	0	0	0	0	0	0	0	0
Nearest PIM-SM Round Robin	0	0	0	0	0	0	0	0	0
Nearest PIM-SM Fuzzy Shortest-path	0	0	0	0	0	0	0	0	0
Nearest PIM-SM Mixed	0	0	0	0	0	0	0	0	0

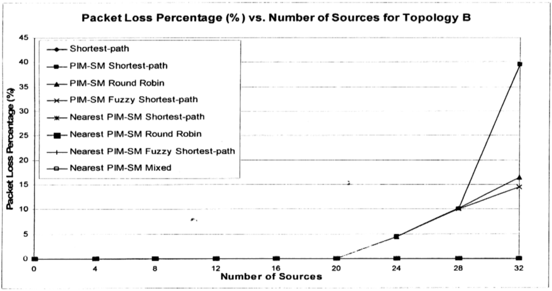

Figure 8.13 *Packet Loss Percentage (%) vs. Number of Sources for Topology B*

Only the PIM-SM extension scheme suffers packet loss in the simulations. This is due to the problems of traffic concentrating near the Rendezvous Point (RP) and "hot-spot" as mentioned earlier. The nearest PIM-SM extension scheme is designed to reduce these problems by allowing anycast packets to be sent towards the nearest service providers without sending to the RP first.

Shortest-path has the worst performance among the three load-balancing schemes used by the PIM-SM extension. The packet loss percentage for the PIM-SM extension with shortest-path increases faster than the other schemes when the traffic load increases from very heavy to extremely heavy (28 to 32 sources). This is because the shortest-path method does not distribute the traffic to other alternate routes even though the shortest-path is congested, which results in a very high packet loss.

The round robin method has better performance than the shortest-path scheme for PIM-SM extension as traffic is distributed evenly among all available routes. However, when the traffic load increases from very heavy to extremely heavy (28 to 32 sources), the round robin method suffers higher packet loss than the fuzzy shortest-path method, which has knowledge about the links. The fuzzy shortest-path scheme has the lowest packet loss percentage among all the schemes as it uses an alternate path when the shortest-path is congested. This capability greatly increases the reliability of the anycast services.\

Topology E

Table 8.11 Packet loss percentage (%) for each simulation sessions in Topology E

Scheme	**Packet loss percentage (%) with *k* number of sources**				
	0	**4**	**8**	**12**	**16**
RIPng extension	0	0	0	0	0
PIM-SM Shortest-path	0	0	0	0	6.20154
PIM-SM Round Robin	0	0	0	0	6.20154
PIM-SM Fuzzy Shortest-path	0	0	0	0	6.20154
Nearest PIM-SM Shortest-path	0	0	0	0	0
Nearest PIM-SM Round Robin	0	0	0	0	0
Nearest PIM-SM Fuzzy Shortest-path	0	0	0	0	0
Nearest PIM-SM Mixed	0	0	0	0	0

Scheme	**Packet loss percentage (%) with *k* number of sources**			
	20	**24**	**28**	**32**
RIPng extension	0.01163	4.10162	9.47986	13.70977
PIM-SM Shortest-path	17.93615	26.19246	28.41030	29.01483
PIM-SM Round Robin	17.93615	26.19246	28.62840	31.19058
PIM-SM Fuzzy Shortest-path	17.93615	26.19224	28.40992	29.01483
Nearest PIM-SM Shortest-path	0.01163	4.10250	9.48061	23.45023
Nearest PIM-SM Round Robin	0	0	2.33531	6.47849
Nearest PIM-SM Fuzzy Shortest-path	0.01163	4.10294	9.48080	13.71109
Nearest PIM-SM Mixed	1.42005	7.47421	11.32439	14.82738

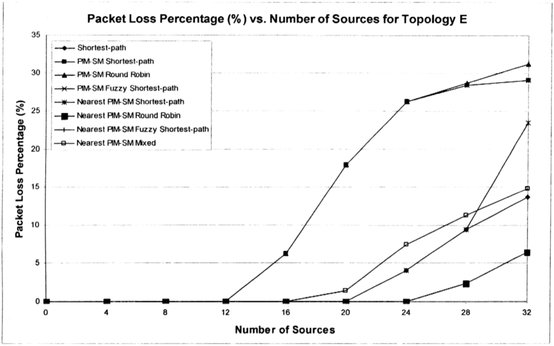

Figure 8.14 *Packet Loss Percentage (%) vs. Number of Sources for Topology E*

The packet loss percentage for the nearest PIM-SM extension is lower than the packet loss percentage for the PIM-SM extension. The effects of the traffic concentration around the RP and "hot-spot" cause the PIM-SM extension performs poorly.

The PIM-SM extension suffers packet loss earlier than the nearest PIM-SM extension. The packet loss percentage for the PIM-SM extension scheme increases very quickly when the traffic load increases from moderate to heavy (16 to 24 sources). The packet loss percentage increases slowly when the traffic load is very high (28 to 32 sources).

The RIPng extension and the nearest PIM-SM extension have lower packet loss percentage than the PIM-SM extension. The packet loss percentage for these schemes increases slowly as the traffic load increases, except the nearest PIM-SM extension with shortest-path when the traffic load is extremely heavy (>28 sources).

Schemes that have knowledge of the links are more likely to reduce the packet loss percentage. The packet loss percentage for the nearest PIM-SM extension with fuzzy shortest-path and mixed load-balancing scheme increase slower than the other schemes when the traffic load continues to increase (Figure 8.14), especially the nearest PIM-SM extension with mixed load-balancing scheme.

The packet loss percentage for the nearest PIM-SM extension with shortest-path scheme increases suddenly when the traffic load increases from very heavy to extremely heavy (28 to 32 sources). This is because the packets will still be sent towards the links that are congested, as this scheme has no knowledge of the links at all. At the speed that the packet loss percentage of the nearest PIM-SM extension with round robin increase when the traffic load is extremely heavy (>28 sources), the packet loss percentage for this scheme will increase rapidly later although it has the lowest packet loss percentage among all the schemes.

8.1.3 Summary

Generally, the schemes that utilize single-path approaches (RIPng extension, PIM-SM extension with shortest-path, PIM-SM extension with fuzzy shortest-path, nearest PIM-SM extension with shortest-path and nearest PIM-SM extension with fuzzy shortest-path, except nearest PIM-SM mixed) have lower end-to-end delay when the traffic load is low and moderate. However, as the traffic load gets heavier, the end-to-end delay for these schemes suffers a sudden and rapid increase. Meanwhile the schemes that utilize purely multi-path routing approaches (PIM-SM extension with round robin and nearest PIM-SM extension with round robin) have a totally different behavior. The end-to-end delay for these schemes are higher when the traffic load is low and moderate, but when the traffic load gets heavier, they are more resilient to a rapid increase (increase at a slower rate). The nearest PIM-SM extension with mixed load-balancing scheme will have both the characteristics of the pure single-path and pure multi-path approach. Its end-to-end delay is low when the traffic load is low and moderate (higher than other schemes with single-path approaches and lower than schemes with purely multi-path approaches) and is more resilient to the rapid increase when the traffic load becomes very heavy (far lower than other schemes with single-path approaches but slightly higher than schemes with purely multi-path approaches).

The nearest PIM-SM extension will perform very similar to PIM-SM extension under certain circumstances. It has the advantages (load-balancing) but overcomes the disadvantages (hot-spot and traffic concentrating around the RP) in the PIM-SM extension. The simulation results for Topology B and Topology E show that the nearest PIM-SM extension scheme is able to reduce these effects significantly.

Among the load-balancing schemes implemented, shortest-path typically has the lowest end-to-end delay and round robin has the highest end-to-end delay when the traffic load is low and moderate. The end-to-end delay of the fuzzy shortest-path is lower than round robin but higher than shortest-path. When the traffic load is very high, the round robin will usually have the lowest end-to-end delay and packet loss percentage due to its capability of distribute traffic evenly amongst all the routes. However, when the traffic load is not able to be distributed properly, fuzzy shortest-path will be the most reliable scheme as it has knowledge about the conditions of the links. The shortest-path simply performs badly in these conditions.