AN ENHANCED ANYCAST ROUTING PROTOCOL: NEAREST PIM-SM EXTENSION WITH LOAD-BALANCING SCHEMES

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ABSTRACT

The primary issue with anycast routing protocol is the tradeoff between performance and reliability. An anycast routing protocol that can provide shorter end-to-end delay does not always has lower packet loss, and vice versa. This paper focuses on achieving short end-to-end delay and low packet loss, and proposes an enhancement to the anycast routing protocol called the nearest Protocol Independent Multicast – Sparse Mode (PIM-SM) extension. This extension supports two load-balancing schemes, i.e. shortest-path and round-robin. The UMJaNetSim network simulator is used as the simulation environment for evaluating the nearest PIM-SM extension. Other necessary protocols such as Internet Control Message Protocol Version 6 (ICMPv6) and Multicast Listener Discovery (MLD) are implemented as well. Simulation results show that the proposed mechanisms for anycast routing improve the performance by reducing end-to-end delay and packet loss ratio.

Keywords*: *Anycast Routing Protocol, Protocol Independent Multicast – Sparse Mode (PIM-SM), Load-balancing schem.

1.0 INTRODUCTION

The Internet Protocol Version 6 (IPv6) [1] introduced several major improvements and services over the current Internet Protocol Version 4 (IPv4). Anycast, one of the new services introduced under the IPv6 specification, promises improvements to the current internetworking environment, such as better service location, generalization of services and policy-based routing. Anycasting is a network service that allows a host, application, or user to locate a server but does not particularly care which server is used, if several servers support the service [2]. In other words, anycasting allows a source node to transmit datagram to a single destination node, out of a group of nodes. A packet addressed to a group's anycast address is delivered to only one (and preferable one) of the nodes in the group, according to the routing protocol's measure of distance. Nodes in anycast groups are specially configured to recognize anycast addresses, which are drawn from the unicast address space [1].

Research shows that anycast routing protocols currently available are only capable of giving satisfactory performance when certain network topology is used [3]. There is no evidence that the anycast routing protocol will work well under other network topologies. PIM-SM [4] is chosen for this research because PIM-SM provides efficient communication for multicast groups with sparsely distributed members [19]. The reason behind this is that PIM-SM does not send any multicast flow to network areas where there is no group member. Moreover, PIM-SM with the use of Candidate-Rendezvous Point (C-RP) can scale well and is more reliable than normal Core-Based Tree (CBT) [5]. Rendezvous Point (RP) is a configured router used as the root of the tree for the anycast address. However, the high overhead of PIM-SM's control messages leads to the increasing processing load on the router and network bandwidth consumption. Thus, modifications are needed in order to improve the performance of PIM-SM.

The problems of using an ineffective load balancing scheme will also affect the anycast routing protocols' performance and reliability. Under normal circumstances, round robin schemes in multicast-anycast extension routing protocol will only outperform shortest-path scheme when there are many on-tree hits and under heavy load conditions. On-tree hits mean that the router that the sender is directly attached to has joined the multicast tree, thus the packets can be routed to the receivers directly. Under other conditions, the round robin schemes will not perform better than the shortest-path load balancing scheme. Besides, by sending all the packets towards the RP, the RP might be overloaded and fail to respond properly. Although PIM-SM does provide failure handling through C-RP, it is more desirable to avoid it from happening in the first place. Based on these observations, this paper proposes to use shortest-path routing for off-tree hits, rather than sending all the packets towards the RP. To accomplish this goal, a new method called the nearest PIM-SM extension, a modification to the PIM-SM extension, is proposed.

The rest of the paper is organized as follows. The next section discusses related works. Section 3.0 presents the proposed nearest PIM-SM extension for anycast routing, and two load-balancing schemes. The evaluation of the performance of the nearest PIM-SM extension using the two different load-balancing schemes is discussed in Section 4.0. Finally, conclusions and future works are presented in Section 5.0.

2.0 RELATED WORK

Metz discussed the benefits of anycast (router and link reduction, simplified configuration, network resiliency and load balancing) in [12], as well as solutions to practical problems in anycast. Hagino and Ettikan also discussed the benefits of anycast and issues regarding anycast in [3]. Dan Li et al. analyzed the performance of PIM-SM in [6]. Anycast has become a popular communication model for Internet Protocol [13]. Webber and Cheng [14] conducted a survey of anycast in IPv6 networks and discussed some of the major problems with network-layer anycast as well as their possible solutions. In the last decade, research on anycast has been carried out worldwide. Shui Yu et al. [11] reviewed the work done on both network-layer anycast and application-layer anycast. Owing that many people are interested in anycast, Hashimoto et al. [15] defined anycast related terms for common use.

Efforts done in proposing and reviewing anycast routing protocol include Dong Xuan et al. [7], K.H Tan et al. [8], Wei Jia et al. [9] and Zhang Li et al. [10]. According to Dong Xuan et al. [7], multi-path approach for anycast routing can balance the traffic load better than single-path routing under heavy traffic. However, the results may not be totally agreeable. The multicast routing protocol used by Dong Xuan et al. [7] is CBTs, a model that may have problems when there is no good network topology. Matsunaga et al. [17] proposed a new anycast routing protocol called Protocol Independent Anycast – Sparse Mode (PIA-SM). PIA-SM is developed from the PIM-SM due to the many similarities between multicast and anycast, with some modifications based on the differences between multicast and anycast. The experimental results verified that the PIA-SM enables routers to forward an anycast packet to an appropriate node of the multiple candidate nodes, as defined in anycast. However, Matsunaga et al. [17] also mentioned the scalability problem of using PIA-SM as the anycast routing protocol in the global network. Lin et al. [16] proposed a load-balanced anycast routing protocol based on Weighted Random Selection method. Lin et al. suggested that server capability information should be propagated along with other information contained in routing tables to provide better load-balance and Quality of Service.

3.0 PROPOSED NEAREST PIM-SM EXTENSION WITH LOAD-BALANCING SCHEMES

The objective of the proposed nearest PIM-SM extension is to obtain equivalent performance of using shortest-path tree while inheriting the load-balancing abilities of the PIM-SM. The proposed protocol aims to reduce the effects of hot spot and traffic concentration around the RP.

The algorithm used by the proposed nearest PIM-SM extension is as follows:

When receiving a unicast/anycast packet
    If the receiving router has group information of the anycast group
        Forward the packet to the nodes that join the anycast group,
        according to the load-balancing scheme applied
    Else
        Forward the packet to the nearest interface having the anycast group address,
        like a normal unicast route table lookup

The proposed nearest PIM-SM extension differs from PIM-SM extension. PIM-SM extension will forward the packet towards the RP if the receiving router does not have the group information of that anycast group.

Two load-balancing schemes, i.e. shortest-path and round robin, are implemented in this work. Shortest-path is a typical single-path routing approach. The received anycast packets will be routed towards the nearest downstream router in the anycast group, according to the routing protocol's measure of distance. Shortest-path is the simplest approach and is easy to implement. However, it has some weak points. It cannot make use of the existence of an alternative route even though the shortest-path is very congested at the moment. The packets will still be sent towards the shortest-path and high packets loss will be experienced. This drawback greatly reduces the reliability of the anycast routing using this scheme.

Round robin is a typical multi-path routing approach. Each interface that has anycast members in the downstream will be selected accordingly in turns. The benefit of using round robin is that it can distribute the traffic load evenly among all the available routes. This behavior can greatly improve the performance of the anycast routing when the traffic load is extremely high. However, this scheme has a setback. The action of distributing the traffic load evenly to all the available routes degrades the performance of the anycast when the traffic load is either low or moderate.

4.0 PERFORMANCE EVALUATION

With the simulation environment that has been created, several scenarios are simulated to observe the performance of each anycast routing protocol. A simulation topology based on the MCI Internet backbone (see Fig. 1) is used to represent 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.

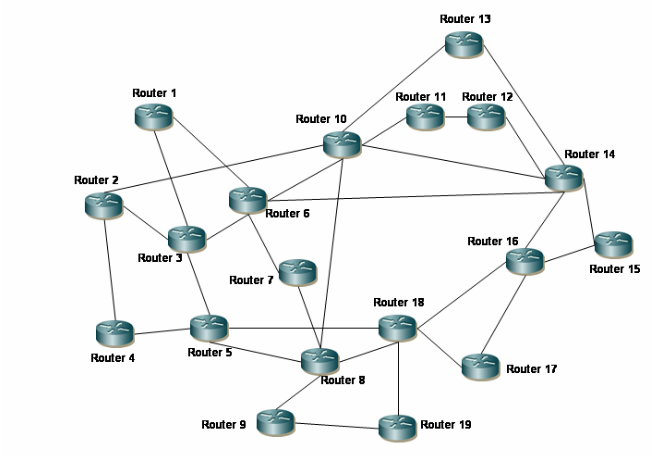

Fig. 1: MCI topology

Table 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 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

Each router is connected to a customer site (IPv6 Broadband Terminal Equipment) 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 1. The anycast group service providers are connected to a customer site as well. The characteristics of the service providers are listed in Table 2.

The distribution of traffic sources and anycast service providers has a great impact on the results of the simulation sessions. This work uses five types of randomly generated traffic sources-service provider distributions (Topology A-E, Fig. 10-14 in Appendix A), each based on the MCI Internet backbone topology for a thorough study on the anycast routing.

The results for Topology A, B, C and D (see Fig. 2-5, and Table 3-10 in Appendix B) denote that the schemes using single-path approaches (PIM-SM shortest-path, nearest PIM-SM shortest-path) have lower average end-to-end delay than the schemes using multi-path approaches (PIM-SM round robin, nearest PIM-SM round robin) when the traffic load is light or moderate (< 20 sources). The average end-to-end delay for all the schemes increases 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 increases at a slower rate and is lower than the schemes using purely multi-path approaches.

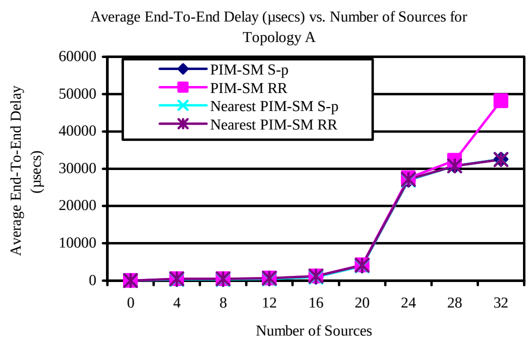

Fig. 2: Average end-to-end delay (µsecs) vs. number of sources for Topology A

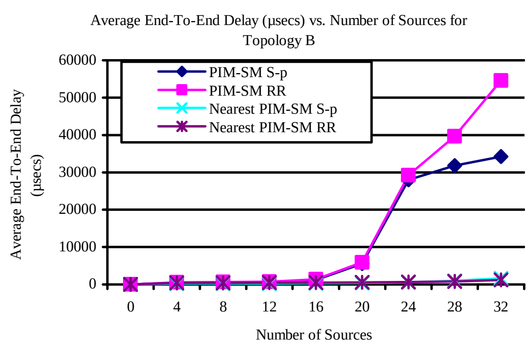

Fig. 3: Average end-to-end delay (µsecs) vs. number of sources for Topology B

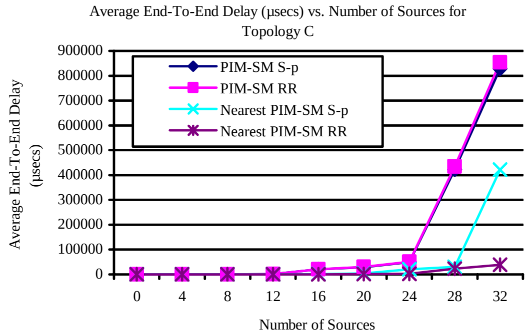

Fig. 4: Average end-to-end delay (µsecs) vs. number of sources for Topology C

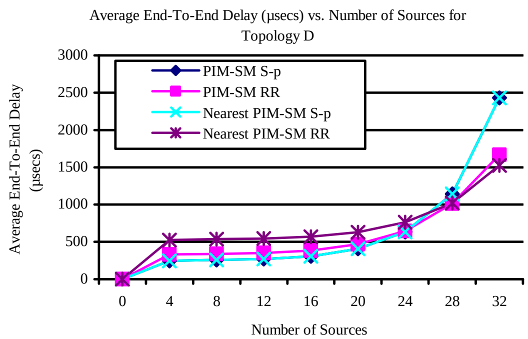

Fig. 5: Average end-to-end delay (µsecs) vs. number of sources for Topology D

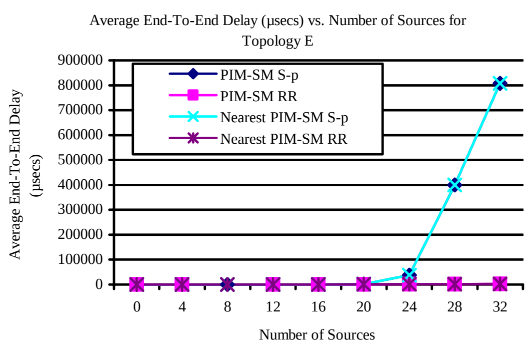

Fig. 6: Average end-to-end delay (µsecs) vs. number of sources for Topology E

The failure of the single-path approach to distribute the traffic load properly is exposed in the simulation results for Topology E (Fig. 6). In contrast, the schemes using multi-path approaches that can distribute the traffic better are performing well.

A typical core-based tree faces the problem of traffic concentrating around the RP and "hot-spots". As a result, the PIM-SM extension faces the same problem. The consequences are exposed in the simulation results for Topology B (Fig. 3) and Topology C (Fig. 4). 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 nearest PIM-SM extension scheme uses a single-path approach for off-tree hits. Off-tree hits mean that the router that the sender is directly attached to has not joined the multicast tree and has no information of the receivers, so the router will have to route the packets towards the RP for the group. As a result, the nearest PIM-SM extension scheme outperforms the PIM-SM extension in all the simulations.

Generally, the nearest PIM-SM extension performs better than the PIM-SM extension and its average end-to-end delay increases slowly when the traffic load increases. The average end-to-end delay for the nearest PIM-SM extension with shortest-path increases suddenly when the traffic load is extremely heavy (28 to 32 sources) due to the failure of the scheme to choose an alternate route when the shortest-path is congested.

The discussion of packet loss will only cover the simulation sessions for Topology A (Fig. 7), Topology B (Fig. 8) and Topology C (Fig. 9) as there is no packet loss in the simulation sessions for Topology D and Topology E. The result for Topology A (Fig. 7) shows that the packet loss percentages for all the schemes are alike because the anycast packets sent use the same routes towards their respective service providers. There is no alternate route available when congestion occurs. Thus, the packet loss percentages for all the schemes are the same.

The result of Topology B (Fig. 8) shows that only the PIM-SM extension scheme suffers severe packet loss. This is due to the problems of traffic concentrating near the RP and “hot-spots” as mentioned earlier. The nearest PIM-SM extension scheme is designed to alleviate this problem by allowing anycast packets to be sent towards the nearest service providers without sending to the RP first.

Between the two load-balancing schemes used by the PIM-SM extension, the shortest-path scheme has the worst performance. The packet loss percentage for the PIM-SM extension with shortest-path increases faster than the other schemes when the traffic source increases (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.

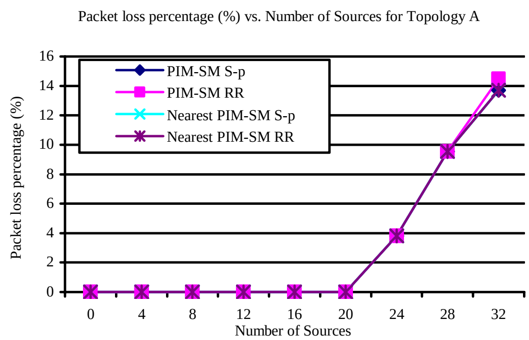

Fig. 7: Packet loss percentage (%) vs. number of sources for Topology A

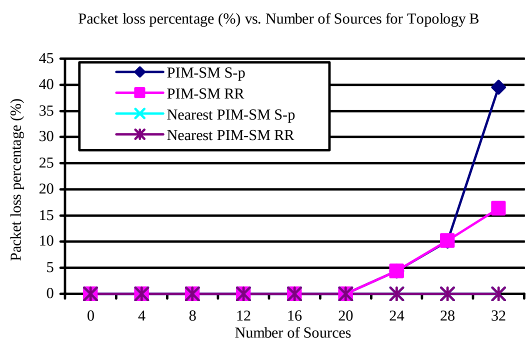

Fig. 8: Packet loss percentage (%) vs. number of sources for Topology B

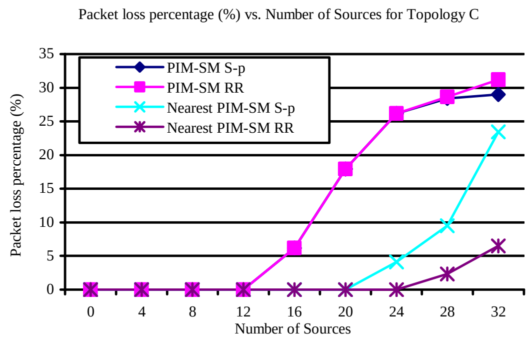

Fig. 9: Packet loss percentage (%) vs. number of sources for Topology C

The result of Topology C (Fig. 9) shows that 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 shortest-path scheme increases suddenly when the number of traffic sources increases. As this scheme has no knowledge of the links at all, the packets will still be sent towards the links that are congested.

In general, the nearest PIM-SM extension has lower packet loss percentage than the PIM-SM extension. The packet loss percentage for these schemes increases slowly as the traffic source increases.

5.0 CONCLUSIONS AND FUTURE WORK

Overall, the schemes that utilize single-path approaches (PIM-SM extension with shortest-path and nearest PIM-SM extension with shortest-path) 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 undergoes 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 performs very similar to PIM-SM extension under certain circumstances. It has the same advantages (load-balancing) but overcomes the disadvantages (hot-spot and traffic concentrating around the RP) of 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.

The number of load-balancing schemes available here is still not extensive. Possible load-balancing schemes for future research include fuzzy round robin, weighted random selection and fuzzy weighted random selection. As servers become increasingly powerful, the implementation of fuzzy logic control that requires high processing power emerges to be a feasible solution for making routing decisions according to the dynamic network condition.

Future research on anycasting may use Open Shortest-Path First (OSPF) for IPv6 as the underlying unicast routing protocol. The implementation of OSPF for IPv6 will allow simulations of a bigger network topology.

APPENDIX A

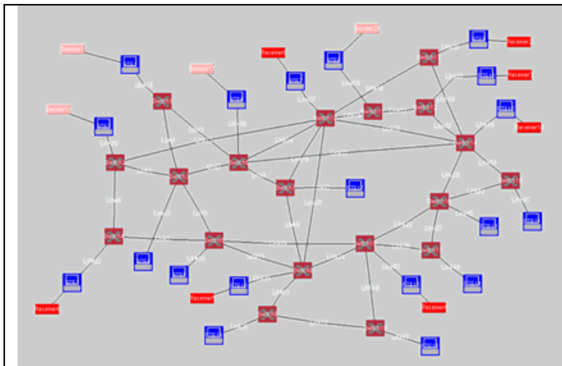

Fig. 10: Sources-service providers distributions for Topology A

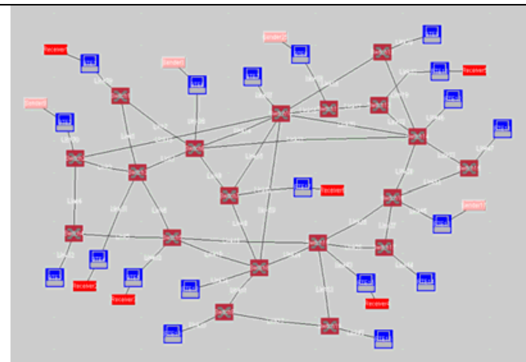

Fig. 11: Sources-service providers distributions for Topology B

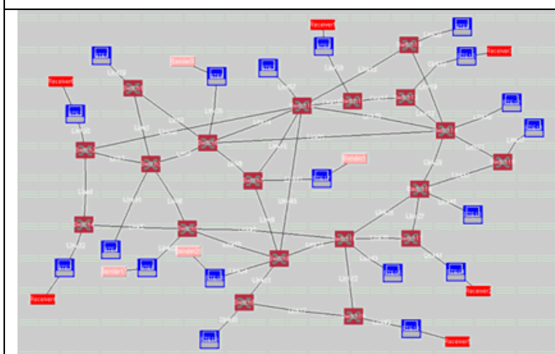

Fig. 12: Sources-service providers distributions for Topology C

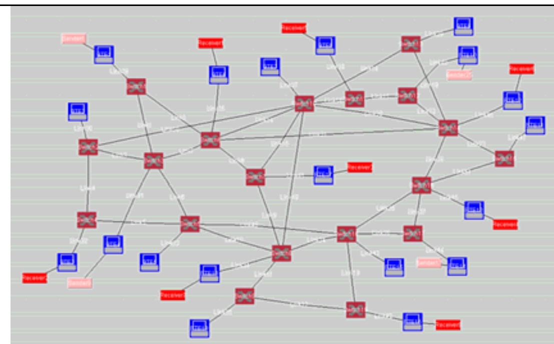

Fig. 13: Sources-service providers distributions for Topology D

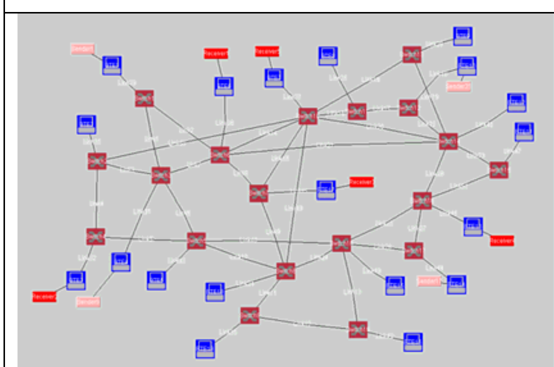

Fig. 14: Sources-service providers distributions for Topology E

APPENDIX B

Table 3: Average end-to-end delay for each simulation session in Topology A

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	4	8	12	16
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
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

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	24	28	32
PIM-SM Shortest-path	3950.28520	27003.82278	30730.27035	32554.22141
PIM-SM Round Robin	4226.32587	27541.82214	32245.40459	48205.52946
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

Table 4: Average end-to-end delay for each simulation session in Topology B

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	4	8	12	16
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
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

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	24	28	32
PIM-SM Shortest-path	5579.30651	28035.97156	31819.23508	34201.70121
PIM-SM Round Robin	5932.55216	29204.51069	39632.80895	54610.45819
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

Table 5: Average end-to-end delay for each simulation session in Topology C

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	4	8	12	16
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
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

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	24	28	32
PIM-SM Shortest-path	1606.12051	37571.17141	399466.04649	807390.75191
PIM-SM Round Robin	510.57225	701.30331	1105.97420	1934.81111
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

Table 6: Average end-to-end delay for each simulation session in Topology D

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources				
	0	4	8	12	16
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
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

Scheme	Average End-to-End Delay (μsecs) with *k* number of sources			
	20	24	28	32
PIM-SM Shortest-path	406.96746	634.32602	1143.01621	2432.63688
PIM-SM Round Robin	466.89487	646.37420	1012.70528	1669.52612
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

Table 7: Average end-to-end delay for each simulation session in Topology E

Scheme	**Average End-to-End Delay (µsecs) with *k* number of sources**				
	0	**4**	**8**	**12**	**16**
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
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

Scheme	**Average End-to-End Delay (µsecs) with *k* number of sources**			
	20	**24**	**28**	**32**
PIM-SM Shortest-path	29429.79722	49625.18748	423043.50059	829040.24432
PIM-SM Round Robin	29804.38942	51070.92790	434969.32043	853674.76138
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

Table 8: Packet loss percentage (%) for each simulation session in Topology A

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

Scheme	**Packet loss percentage (%) with *k* number of sources**			
	20	**24**	**28**	**32**
PIM-SM Shortest-path	0	3.81319	9.53741	13.70729
PIM-SM Round Robin	0	3.81363	9.53741	14.47958
Nearest PIM-SM Shortest-path	0	3.81385	9.53759	13.70729
Nearest PIM-SM Round Robin	0	3.81341	9.53759	13.70746

Table 9: Packet loss percentage (%) for each simulation session in Topology B

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

Scheme	**Packet loss percentage (%) with *k* number of sources**			
	20	**24**	**28**	**32**
PIM-SM Shortest-path	0	4.37523	10.10091	39.53369
PIM-SM Round Robin	0	4.37523	10.21893	16.38008
Nearest PIM-SM Shortest-path	0	0	0	0
Nearest PIM-SM Round Robin	0	0	0	0

Table 10: Packet loss percentage (%) for each simulation session in Topology E

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

Scheme	**Packet loss percentage (%) with *k* number of sources**			
	20	**24**	**28**	**32**
PIM-SM Shortest-path	17.93615	26.19246	28.41030	29.01483
PIM-SM Round Robin	17.93615	26.19246	28.62840	31.19058
Nearest PIM-SM Shortest-path	0.01163	4.10250	9.48061	23.45023
Nearest PIM-SM Round Robin	0	0	2.33531	6.47849

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