ISSN 2047-3338

Optimized Placement of Gateways for Routing Protocols in Wireless Mesh Networks

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Abstract— **Due to the multi-hop nature combined with the relative stable and static topology, Wireless Mesh Networks are considered as the future candidate to provide the broadband wireless access in the user's premises. Unlike the Mobile Ad-hoc Networks, Wireless Mesh Networks are under the authority of a central administration having built in infrastructure. Previous studies have established that the placement of Gateway routers inside the Wireless Mesh Networks' topology have a great impact on the network overall performance. This paper investigates the response of different routing protocols to the Gateway placement in the Wireless Mesh Networks in terms of routing overhead, network latency and Packet Delivery Ratio. Two different scenarios have been extensively simulated with different number of network flows and the performance of these routing protocols has been analyzed. The simulation results show that overall the proactive routing protocol outperforms the reactive one, while the Gateways placed at the center of the network topology enhances the network performance.**

Index Terms—**Wireless Mesh Networks, Networks, Gateway, Router, AODV and OLSR**

I. INTRODUCTION

WIRELESS Mesh Networks (WMNs) [1] are characterized as self-healing, self-organizing and self-configuring multi-hop wireless networks. These networks historically evolved from the Mobile Ad-hoc Networks (MANETs) [2], where the backbone routers play the role of relays to forward the end-users data. However, there is a rudimentary difference in both these technologies in terms of network's deployment and their capabilities to provide the services to the end-users. MANETs are specialized networks used in emergency like situations e.g., natural disasters and military operations, where the network is deployed on ad-hoc basis to provide the connectivity between the users. The notion of 'node' in MANETs is a generating as well forwarding entity. Secondly, due to the ad-hoc nature of the network, there is no permanent infrastructure and the network as a whole is not in the administrative domain of a central authority. The nature of network accommodates the mobility of the nodes from moderate to extreme levels. WMNs, on the other hand, consist of multi-hop wireless routers which are static and have stable and permanent power supplies. WMNs have an edge over MANETs due to their ability to provide the wireless broadband in the user's premises [3]. These networks normally consist of end-users nodes called Mesh Clients (MCs). These MCs are connected to the WMNs routers called Mesh Access Points (MAPs) through their wired or wireless interfaces. The wireless backbone routers, called Mesh Points (MPs), act as relay nodes in WMNs. The whole backbone is connected to the Internet via special routers called Mesh Gateways (MGs), which have wired or wireless connectivity to the Internet cloud. Typical WMNs is shown in the Fig. 1, where MC's are connected to the MAPs which act as data aggregation points in the network. MAPs are further connected to the MPs, which forward this data from the MAPs towards the GWs of the WMNs. The GWs are further connected to the Internet.

Based on the MCs capability to form an ad-hoc network among themselves, WMNs can be further divided into three categories [1]. When the MCs are capable to form an ad-hoc like network among themselves as well as having connectivity to the WMNs backbone trough the MAPs, the network is called hybrid mesh. On the other hand, if the MCs are directly connected to the WMNs backbone without having ad-hoc

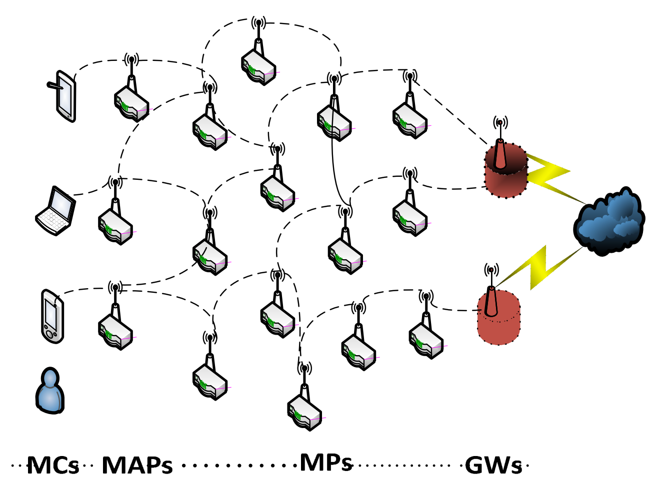

Fig. 1: Wireless Mesh Networks

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capabilities, the network is called hierarchical mesh. When the end nodes MCs only form the ad-hoc network without having a connection to the WMNs backbone, the network is called flat mesh. Due to the nature of WMNs, the flow of user's data is always from the MCs to GWs or vice versa. GWs placement in the network can significantly affect the performance of the network. Since all the data to/from the users premises accumulates at the GWs of the WMNs, their placement in the network backbone can considerably affect the performance in terms of effective throughput and delays. Several studies have addressed the issue of GWs placement inside the WMNs backbone for capacity enhancement.

Routing determines the end-to-end path between any pair of source-destination and hence plays a very imperative role in the network connectivity and overall system performance. The routing protocols developed for MANETs can be used in the WMNs keeping in view the same multi-hope nature of both these networks. The IEEE 802.11s task group [4], established for providing the mesh capabilities in the IEEE 802.11 based Wireless Local Area Networks (WLANs) [5], have considered the already present routing protocols for MANETs to be utilized in the WMNs [4]. However, the performance of these routing protocols should be meticulously investigated for their viability to be used in WMNs due to the different nature of these networks from its wireless predecessors. The routing protocols designed for the MANETs tries to address the issue of reach-ability only [6], where the routing metric is the hop count in almost all the cases. The hop count works well in the MANETs keeping the frequently changing topologies of these networks due to mobility. However, this issue of routing metric design has been gravely addressed in several studies for WMNs due to their entirely different applications [7].

While designing routing metric for the WMNs, based on the already existing protocols of MANETs, is a separate imperative issue; this paper investigates and analyzes the performance of these protocols in the prospective of the GWs placement in the wireless network backbone. The GWs placement, as always the source or destination of the user's data in the WMNs, can affect different routing protocols' performance in terms of the routing overhead, connectivity, reach-ability and throughput. Similarly, different routing protocols can react differently to the gateway's placement inside the WMNs backbone.

The rest of this paper is organized as follow: In Section 2, a brief discussion is given about relevant work. Section 3 briefly describes two routing protocols used in the comparative analysis. In Section 4, we present different WMNs scenarios for placement of GWs at different regions of the network. This is followed by the extensive simulation study in Section 5 outlining the best routing protocol for different scenarios. Finally, Section 6 concludes our work and gives direction for future study.

II. RELATED WORK

Various routing protocols have been analyzed comparatively for their performance behavior in different settings and scenarios. In the previous studies, MANETs have been considered as the candidate testing network where the selection of a certain routing protocol has been proposed based on its efficiency, response time, throughput enhancement and improved connectivity. In their comparative study P. Johansson et al. [8] have considered the scenario based setup where the appropriate protocol has been proposed based on the nodes mobility. Their study is relevant to MANETs only as mobility is the very characteristics of these types of networks. In [9], the authors have studied the behavior of routing protocols with topology changes, and other network dynamics. The authors in [10] have addressed the performance evaluation of two on-demand routing protocols and their comparative analysis has proven that each routing protocol internal mechanism have a huge impact on the overall performance of the network. The work of [11] have considered different routing metrics instead of the by-default hop count for Dynamic Source Routing (DSR) [12] and their study proves that Extended Transmission count (ETX) outperforms the other metrics. The comparison of routing protocols in MANETs, in terms of power consumption, has been comparatively analyzed by [13]. In [14], the authors have analyzed the MANETs routing protocols performance by considering the ad-hoc grid in e-health applications setup. All of the above mentioned studies have focused on the MANETs and the related issues have been outlined in respect to the routing protocol's behavior.

In WMNs, J Chen et al. [15] have conducted the comparative simulation study of a reactive and proactive routing protocol. The proactive protocol has been proved to be efficient for large WMNs backbone with some mobility. In their research J Wang et al. [16] have addressed the issue of MRs and GWs placement inside the WMNs backbone for overall network performance improvements. The authors in [17] have addressed the gateway selection problem in the large WMNs networks. To minimize the congestion on the individual network links, they have defined a heuristic based cost function which further minimizes the total routing traffic in the mesh backbone. The performance of a set of reactive and proactive routing protocols have been studied in [18], where the authors have analyzed these protocols with regard to network load, mobility of the nodes and the network size. Similar to [16], the gateways deployment inside the mesh backbone has been studied in one of the study of [19], where the authors have proved it to be an NP-hard optimization. They have further formulated the problem with a linear program and developed the heuristics algorithm which proved to be cost efficient. On a similar way, the gateway placement problem has been addressed by [20], where the authors have considered a constraint network model and theoretical analysis has been provided to evaluate the traffic demands, based on which the location of Gateways is determined.

In this paper we have compared both reactive and proactive routing protocols in Wireless Mesh Networks based on their routing overhead, Packet Delivery Ratio and network latency. Our study is different from all of the above cited work because we have investigated the problem with respect to the Gateways routers placement in the wireless backbone, while these studies have addressed either the Gateways placement problem alone or the routing protocol analysis by considering the flat, hybrid or hierarchical WMNs topologies. To the best of our knowledge, this is the first study outlining the routing protocols performance analysis in terms of GWs placement inside the WMNs backbone.

III. AN OVERVIEW OF REACTIVE AND PROACTIVE ROUTING PROTOCOLS

Routing protocols can be categorized as reactive (on-demand) and proactive (table driven). In the reactive routing protocols, the routes between any source and destination are established as when and where necessary. In essence, the routing module reacts to the demands of the source which needs to find some route to the destination for sending some data. The protocols are simple in operation and the intermediate routers only need to keep one entry for each path/route between any source-destination pair. The advantage of these types of protocols is the simple operation and less routing overhead. The Ad-hoc On Demand Distance Vector (AODV) [21] and Dynamic Source Routing (DSR) [12] belong to this category of routing protocols.

In proactive/table driven routing protocols, the route from each node is pre-established to any other node in the whole network. It is table driven approach as the routers frequently update each others about their locations. Thus large tables are maintained on each routers the size of which increases linearly with the number of routers/nodes in the entire network. Since, these routing protocols always maintain fresh routing tables for each node pair across the network, therefore, whenever a source node wants to send some data to any destination; there is no need to establish the route first. Destination Sequenced Distance Vector (DSDV) [22] and Optimized Link State Routing (OLSR) [23] belong to this routing protocols category.

AODV is a reactive routing protocol which establishes routing paths between any source-destination pair in a network. When a source wants to send some data to a destination, it generates a route request message called RREQ packet, which is broadcasted to all of its neighbors. The RREQ packet contains the source and destination nodes IP address along with RREQ ID and hop count. The RREQ ID and source node's IP uniquely identifies a specific route between any source-destination pair. Upon receiving the broadcast RREQ from a source node, all of its neighbors first check the destination IP field inside the packet header. If the route request is intended for one of them, a RREP is unicasted to the source node and the route is established. If the RREQ's destination IP does not match with that of the neighbor's one, the route request packet is broadcasted by the neighbors to their neighbors. This broadcast process continues until the request reaches to the intended destination. The destination node, upon the reception of RREQ, unicasts a RREQ packet to the source node through the node from which it has received the first RREQ. The path is established when the RREP packets reaches the originating source node.

In AODV protocol, the intermediate nodes can also return a path to the destination if they have a fresh entry which matches the source-destination IP addresses of the RREQ packet. The route errors in the AODV are reported through RERR packets and any broken link, in the end-to-end path, is reported back to the source node for establishing a new alternative path for the same destination.

The OLSR routing protocol is proactive in nature and is based on the table driven forwarding mechanism. The topology learning is performed with the optimized version of the link state mechanism, where the neighbors exchange the links information with each other. OLSR was specifically developed for MANETs in which the link state information has been optimized to reduce the network level dissemination of routing overhead. The enhancements of the link state algorithm is achieved through the Multi Point Relays (MPRs), where the link state information is selectively exchanged by these specific nodes among each other. This mechanism highly reduces the exchange of routing overhead during the topology learning and routing table update phases. Network nodes select their MPRs and exchange their links state information with them only. The nodes which are selected as MPRs by some neighbor nodes announce this information periodically in their control messages. The OLSR protocol routing paths calculation is achieved in four phases. In the first phase, all the nodes in the network learn about their one and two hop neighbors through the exchange of 'HELLO' messages which is followed by the MPRs selection in the second phase. In third phase, each node broadcasts Topology Control (TC) messages, which contains information of the multipoint relays selectors of these nodes. Multipoint selectors are those nodes which have selected a specific node as MPR in the second phase. The information from TC messages is extracted and is fed to the network topology table by each node. In the final phase, each node calculates the routing tables from the topology tables as discovered in the third stage.

IV. SIMULATION SCENARIOS

The performance of the two reactive and proactive protocols was analyzed by considering two different network set ups. In the first scenario, a WMNs consisting of 50 nodes was considered forming the static topology of the network, as shown in the Fig. 2. 8 mesh routers were considered as the MAPs of the network and were placed at the four corners of the topology. In this scenario, the Gateway router was placed at the center of the network. A total of 45 end nodes/MCs were configured who generate UDP flows at a constant rate of 128kbps each. IEEE 802.11b was considered as the Medium Access Control mechanism and the grid topology was considered during the simulation. The routers were placed at an equal distance of 150m from one another. In the second scenario, a network topology with the same number of nodes and with the same set of parameters was considered. As shown in Fig. 3, the Gateway router was placed at the extreme right hand side of the network topology while the end users/MCs are accessing the mesh backbone placed at the extreme left. The number of MCs was kept the same as in the previous scenario.

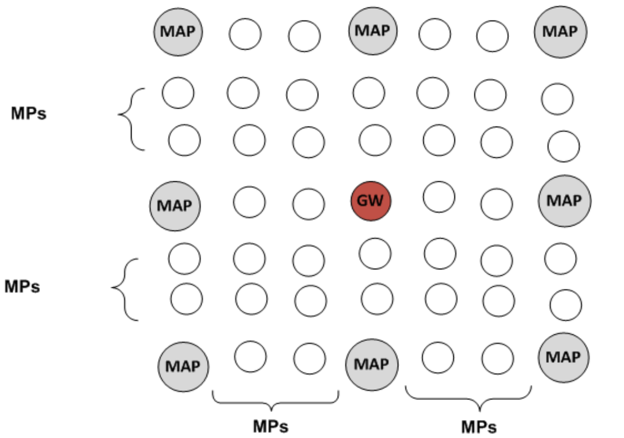

Fig. 2. Scenario 1- Gateway placement at the Center of Network topology

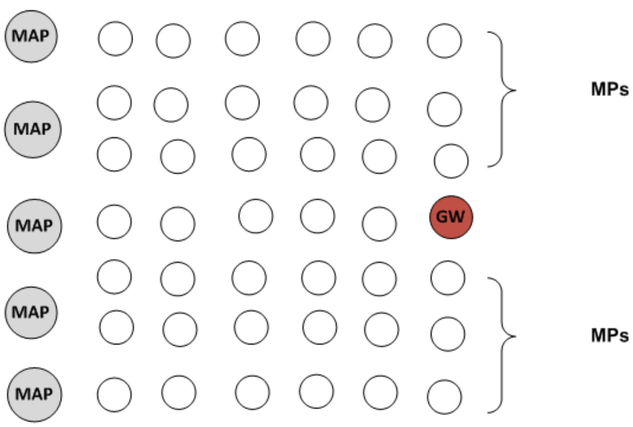

Fig. 3. Scenario 2- Gateway placement at the edge of Network topology

Both scenarios were simulated by using the Network Simulator (ns-2) [24]. With this simulation setup, the performance of AODV and OLSR was measured in terms of routing overhead, network latency and the Packet Delivery Ratio (PDF) for different number of flows.

V. RESULTS ANALYSIS

In this section, the performance analysis of both AODV and OLSR is presented considering two different scenarios as discussed in the Section 4. The routing overhead, network latency and Packet Delivery Ratio of both protocols were obtained considering the same simulation environment. The simulation was repeated 10 times and the average values were plotted in order to build confidence in the results obtained.

Routing Overhead: Routing Overhead refers to the number of packets generated by the routing protocols for the route establishment and maintenance.

Network Latency: Network Latency refers to the total average time it takes for the application layer's packets to reach from the source nodes to the destination nodes. It is recorded when a data packet is transmitted from the source node till it is received by the destination node.

Packet Delivery Ratio: The Packet Delivery Ratio refers to the ratio of the number of packets successfully delivered to the total number of packets generated by the applications of the source nodes. This parameter measures the throughput of the network.

As shown in Fig. 4(a) and Fig. 4 (b), AODV outperformed OLSR by producing less number of routing overhead across different number of flows in both scenarios. The reason for this less number of routing overhead is that AODV is on demand routing protocol and the routing requests, and hence the route reply, packets are only sent as when required by the source nodes. The static topology further increases its efficiency due to less link breakages. However, the routing overhead increases with an increase in the number of generated flows by the source nodes. On the other hand, the OLSR produced more routing overhead as it maintains the routing tables irrespective of the number of flows. Fig. 4(a) and Fig. 4(b) comparatively analyze the routing overhead of the two different scenarios as mentioned in the Section 4. Regarding the gateway placement, the routing protocols performed almost the same in both scenarios. The reason is, for AODV, theoretically; the same number of RREQ and RREP are sent in both scenarios irrespective of the gateway placement. However, there is a marginal decrease in the routing overhead in case of AODV in Scenario 1 as can be seen in the Fig. 4(a) and Fig. 4(b). The reason is that the intermediate routes might have fresh routes to the destinations in most of the cases and the RREQ packet is not flooded from the point of fresh intermediate routers because of the Gateways less distance from the MCs and MAPs. OLSR's routing overhead performance almost remained the same for both the Scenarios.

Fig. 5 depicts the network latency experienced by the data packets inside the network for both protocols and for both scenarios. OLSR outperformed AODV by producing less network latency in both scenarios, comparatively. The reason is because the OLSR maintains the routing paths irrespective of data session start and the paths from each node to any other node are readily available. Secondly, AODV searches the paths with the network wide flooding mechanism, where the path is returned by the destination without counting any specific metric. On the contrary, OLSR takes the minimum hop count as the routing metric and hence this contributes to the overall latency of the network. Fig. 5 also shows the performance of both protocols in the case of Gateway placement. As can be seen from the graph, both protocols performed better comparatively when the GW was placed in the middle of the network topology. The reason is that, since the source nodes MCs in the case of Scenario 1 as presented in Fig. 2 have small path length as compared to the one in Fig. 3; where the GW is placed at the extreme right of the network topology. The path length is the number of links in a path from source to destination nodes. With increasing the number of links, the average cumulative latency of the network increases. The second reason for this high latency for both protocols in the Scenario 2 is that all the data from the MCs passes through the same links and the number of disjoint paths are less as compared to scenario 1.

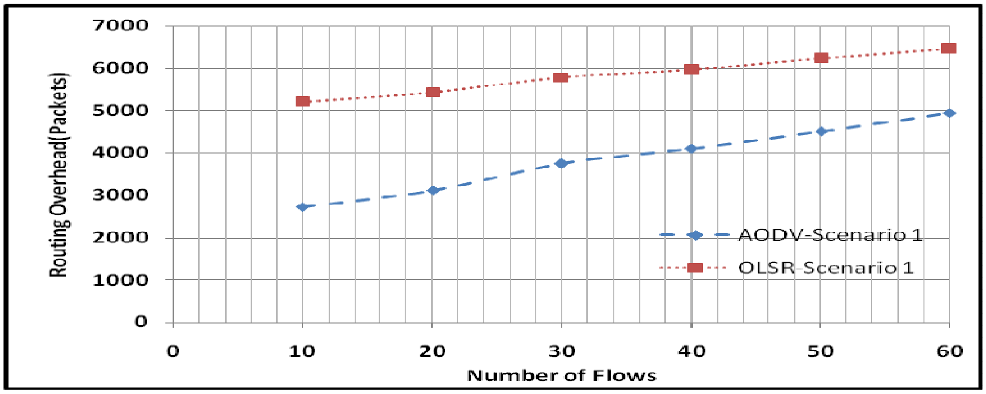

Fig. 4(a): Routing Overhead in Scenario 1

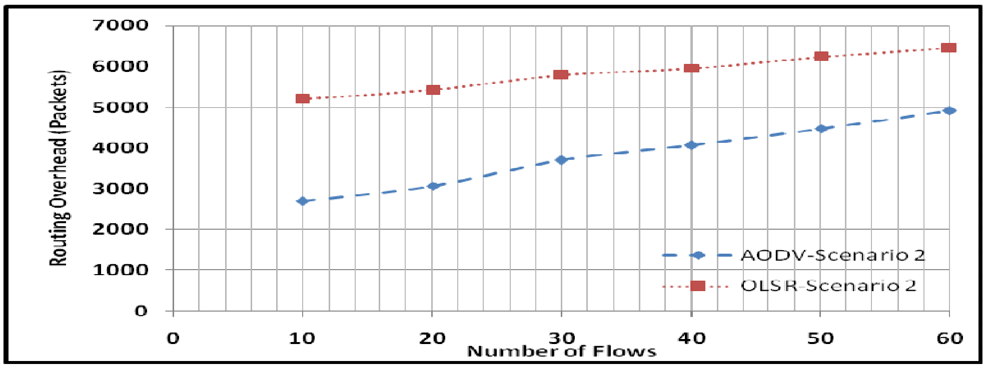

Fig. 4(b): Routing Overhead-Scenario 2

This increases the total cumulative load on the individual links which results in more congestion hence the end-to-end delay increases. Fig. 6 shows the average Packet Delivery Ratio of both protocols in both scenarios. As can be seen from the results, OLSR once again outperformed AODV in terms of Packet Delivery Ratio. The reason is that of OLSR's better path calculation mechanism as compared to AODV. Since AODV's only focus is on finding the path to the destinations, OLSR keeps the notion of better path to the destination by considering the minimum number of links between the source and destination during the route calculation phase. The figure also depicts that the Packet Delivery Ratio decreases as the number of flows increase. This is because with an increase in the number of flows, there is more chance of network wide congestion in both cases and hence the number of dropped packets increases.

Both protocols performed better comparatively in the case of Gateway placement in the middle of the topology as in Fig. 2. This is because, when the GW is in the middle of the network, there is less chance of congestion as compared to the scenario of Fig. 3. In case of Fig. 2's scenario, since all the node are injecting the flows from different locations passing through the disjoint links and hence there is less chance of congestion over the links as compared to that of the scenario of Fig. 3.

VI. CONCLUSION

Wireless Mesh Networks are promising access technology to be deployed as a future broadband solution in the user premises. The static nature of the WMNs routers enhances its capability to provide more throughputs to the end users as compared to the traditional MANETs. The multi-hop topology of the WMNs further enhances the scalability of the wireless backhaul. In this paper, we have investigated the behavior of reactive and proactive routing protocols in the WMNs in response to the Gateway routers placement inside the network topology. The performance of these protocols was measured in terms of routing overhead, network latency and Packet Delivery Ratio. Two scenarios were configured with the same simulation parameters, both having the Gateways routers placed at different locations of the network topology. The simulation results show that the proactive protocol (OLSR) outperforms the reactive routing protocol (AODV) in terms of network latency and the Packet Delivery Ratio.

However, AODV proved to produce less routing overhead for all the scenarios and for any number of flows. In terms of Gateway placement, both routing protocols performed better when the Gateway router was placed in the center of the network topology. In future, we are going to analytically investigate the effects of Gateway routers locations on various routing protocols through mathematical modeling. The will be further investigated by including the multiple radios multiple channels capabilities in the WMNs through simulation studies.

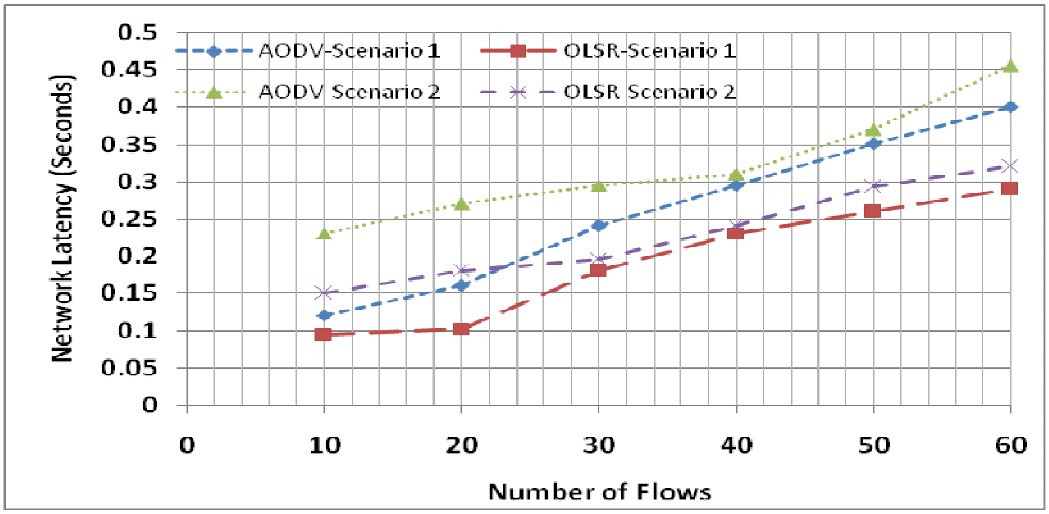

Fig. 5: Network Latency

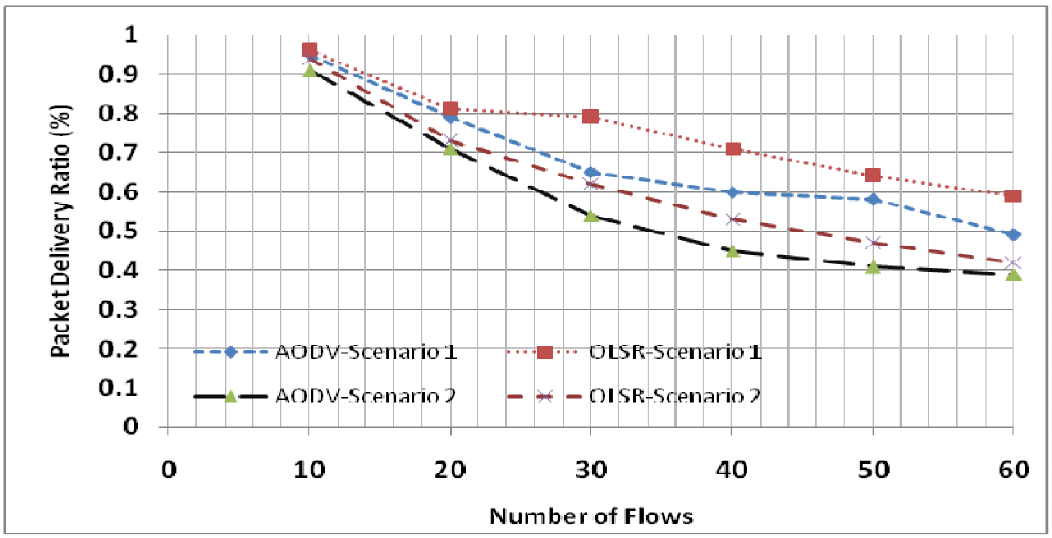

Fig. 6: Packet Delivery Ratio (%age)

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