Performance Comparison of Proactive and Reactive Multicast Routing Protocols over Wireless Mesh Networks

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Summary
Multicast routing is a key technology for modern communication networks. It sends a single copy of a message from a source to multiple receivers over a communication link that is shared by the paths to the receivers. This is especially appropriate in wireless environments where bandwidth is scarce and many users are sharing the same wireless channels. In particular, for WMNs, multicast can represent a huge enhancement of the network capacity by taking advantage of links which can be shared by multiple users to receive the same data, which is transmitted only once. To support multicasting, several multicast routing protocols are designed for Internet and Ad hoc networks. However, no specific multicast routing protocol is designed for WMNs. Therefore, the performance comparison of existing multicast routing protocols over wireless mesh networks is essential in order to analyze their behavior and effectiveness. This paper presents the simulation and analysis of the performance of existing proactive and reactive multicast routing protocols over WMNs. Three prominent multicast routing protocols are selected for performance comparison; they are On Demand Multicast Routing Protocol (ODMRP), Multicast Ad hoc On Demand Distance Vector (MAODV) Protocol and Multicast Open Shortest Path First (MOSPF). Among them, MOSPF is a proactive routing protocol while MAODV and ODMRP are reactive multicast routing protocols. MAODV fabricates and maintains a shared multicast tree for each multicast group and ODMRP is a mesh-based approach and uses a forwarding group concept. Our aim is to investigate the relative strength and weaknesses of each protocol.
Key words:
MAODV, MOSPF, Multicast Routing Protocol, ODMRP, Wireless Mesh Networks

1. Introduction

Wireless Mesh Networks (WMNs) have recently gaining increasing attention and have emerged as a technology with great potential for a wide range of applications. WMNs are dynamically self-organizing and self-configuring, with the nodes in the network automatically establishing an ad hoc network and maintaining the mesh connectivity [1] [2]. WMNs consist of mesh routers and mesh clients, where mesh routers have minimal mobility and form the backbone of WMNs. They provide network access for both mesh and conventional clients. Mesh clients can be either stationary or mobile, and can form a client mesh network among themselves and with mesh routers. There are three standards of WMNs which are IEEE 802.11 mesh networks, 802.15 mesh networks.

Applications that support one-to-many or many-to-many communications can be benefited from the broadcasting nature of this type of wireless networks. In order to facilitate communication within a group of users, multicast routing protocols are used to discover routes between nodes. Multicast has enormous impact since it overcomes the overheads of the unicast routing protocol.

Internet standards and IP multicast were developed almost at the same time. Nonetheless, the development of multicast compared to the World Wide Web (WWW) and the HyperText Transfer Protocol (HTTP), has been very slow [3]. According to Almeroth [4], multicast is in its infancy while the WWW's success, influence, and use seem totally pervasive. The first protocol designed for multicasting in Layer 3 is Distance Vector Multicast Routing Protocol (DVMRP) [5]. Subsequently, several other protocols have been designed, such as Multicast Open Shorted Path First (MOSPF) [6], Core Based Trees (CBT) [7], Protocol Independent Multicast for dense and sparse mode [8] - [10].

Unlike typical wired networks protocols, routing is extremely challenging in ad hoc networks due to its dynamic topology changes. The routing protocols must address a diverse range of issues such as power consumption, bandwidth limitation etc. To support multicasting in such type of networks, many routing protocols have been proposed in the last decade, such as MAODV (Multicast Ad-hoc On-Demand Distance Vector) protocol [11] [12], AMRoute (Ad-hoc Multicast Routing Protocol) [13], On-demand Multicast Routing Protocols (ODMRP) [14], Core-Assisted Mesh Protocol (CAMP) [15].

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Multicast routing protocols can be classified in two general categories, they are: proactive and reactive multicast routing protocols. Proactive methods maintain routes to members of multicast group, as well as the nodes which are not in any multicast group. They are also known as table-driven methods. DVMRP, MOSPF, PIM are example of proactive multicast routing protocol. Reactive methods are based on demand for data transmission. Routes between hosts are determined only when they are explicitly needed to forward data packets. They are also called on-demand methods. Multicast protocols like ODMRP, MAODV use reactive methods. There is another category which is the combination of proactive and reactive methods, known as 'Hybrid' method. This method is not described as this is out of the scope of the paper.

Performance comparison among some set of routing protocols are already reported by the researchers in papers [16]–[21] and many more. These performance comparisons are mostly carried out for ad hoc networks; a few for WMNs. In paper [2], authors quantify the performance differences of Minimum Cost Trees (MCTs) and Shortest Path Trees (SPTs) algorithms in WMNs; not the protocols. Therefore, the performance comparison of proactive and reactive multicast routing protocols is essential in order to analyze their behavior and effectiveness. Moreover, the performance comparison among ODMRP, MAODV and MOSPF is not performed before over WMNs environments as well as ad hoc networks environments. For this reason, evaluating the performance of existing multicast in wireless mesh environments is still an active research area.

The remainder of the paper is organized as follows. Protocols selected for performance comparison are described in Section 2 along with their relative merits-demerits and proposed enhancement. Section 3 explains the simulation environment, scenarios and its important performance parameter and metrics. Simulation results are discussed in section 4. Finally, in section 5, conclusions are drawn.

2. Protocols Descriptions

In this section, ODMRP, MAODV and MOSPF multicast routing protocols are described. Their relative advantages and limitations are also mentioned along with the proposed extensions of each protocol.

2.1 On-demand Multicast Routing Protocols (ODMRP)

ODMRP is a mesh-based scheme and uses a forwarding group concept (only a subset of nodes forwards the multicast packets via scoped flooding). A soft state approach is taken in ODMRP to maintain group membership. Therefore, no explicit control message is required to leave the group. ODMRP applies "on-demand" routing approach to avoid channel overhead. Its routing mechanism consists of a request phase and a reply phase. To configure the forwarding mesh for multicast group, it uses two types of control packet: *Join Query* and *Join Reply*. When a node has information to send but no route to the receiver, a *Join Query* message is broadcasted to the entire network. When a *Join Query* packet reaches to the multicast receiver, it creates a *Join Reply* packet that is broadcast to its neighbors. When a node receives a *Join Reply*, it checks if the next node address of one of the entries matches its own address. If it does, the node realizes that it is on the path to the source and thus becomes a part of the forwarding group (FG) for that source by setting its forwarding group flag. It then broadcasts its own *Join Reply*, which contains matched entries. The next hop IP address can be obtained from the message cache. This process construct (or update) the routes from sources to receivers and builds the forwarding group. Membership and route information is updated by periodically (certain interval times) sending *Join Query* packet. Nodes only forward data packet if they belong to the forwarding group or if they are multicast group members.

Since ODMRP uses a subset of forwarding nodes to forward packets to receiver via scoped flooding, it suffers only minimal data packets loss. It is robust to node mobility. Moreover, it has low channel and storage overhead because of its on-demand nature. However, its control overhead varies with node mobility as well as number of senders. Use of sender-initiated mesh construction method results in larger mesh and numerous unnecessary transmissions of data packets compared to a receiver-initiated mesh construction approach [22].

Several extensions of ODMRP have been proposed by the researchers. ODMRP with Multi-Point Relay (ODMRP-MPR) is proposed by Zhao [23]. In this extension, they induct multipoint relay technique to reduce the control overhead, obtain high scalability and effectively solve the unidirectional link problem of wireless communication. Lee [24] proposed another extension, referred to as PatchODMRP. To deal with the frequent mesh reconfiguration, PatchODMRP deploys a local patching scheme where each FG node keeps checking if there is a symptom of mesh separation around itself. When an FG node finds such indication, it tries to patch itself with a local flooding. Oh [25] describes the impact of route refresh interval on protocol overhead and thus efficiency. They proposed an enhancement of ODMRP (E-ODMRP) with refresh rate dynamically adapted to the environment. E-ODMRP reduces the packet overhead by up to a half yet keeping a packet delivery ratio comparable to that of the original ODMRP. To handle unidirectional links, ODMRP-ASYM [26] is proposed. The main advantages it achieves includes, control overhead comparable with ODMRP even in highly asymmetric topologies, virtually no performance degradation in presence of unidirectional links (while ODMRP typically suffers up to 15% drop in delivery performance), and connectivity maintenance even if no bidirectional path exists between sender and receiver. Narshima [27] enhanced ODMRP by improving the adaptivity to node movement patterns. They enhanced ODMRP in such a way that it transmits control packets only when necessary, reconstructs routes in anticipation of topology changes, improves hop-by-hop transmission reliability, and eliminate route acquisition latency. A new technique for supporting QoS routing in ODMRP is proposed in [28], where the authors developed a method for estimating bandwidth. QoS routing for ODMRP improves network performance in presence of mobility, by selecting suitable paths. Pathirana and Kwon [29] proposed another extension of ODMRP named RODMRP that offers more reliable forwarding paths in face of node and network failures. In this extension, a subset of the nodes that are not on forwarding paths rebroadcast received packets to nodes in their neighborhoods to overcome perceived node failures.

2.2 Multicast Ad Hoc On-demand Distance Vector Protocol (MAODV)

MAODV protocol is the multicast extension of AODV [30] which is used for unicast traffic. It creates a group tree, shared by all sources and receivers for a multicast group. The root of each group tree is designated as a group leader which maintains multicast group sequence number. MAODV discovers multicast routes on demand using a broadcast route-discovery mechanism. A mobile node originates a *route request* message and broadcast when it desires to join a multicast group. A member of the multicast tree (intermediate node) with a current route to the group leader or group leader himself responds to request message with a *route reply* message. If source node receives multiple reply messages for its route request, route is decided based on the freshest sequence number or the least hop count when sequence numbers are identical. Subsequently a *multicast activation (MACT)* message is sent by the source node to sets up multicast state between the newly joined receiver and the shared tree. The broken links are detected with the help of periodic hello packets broadcasted by each node in the network. The node downstream of the break point is responsible for repairing the broken link.

Unicast and Multicast both operations can be handled using AODV and its extension MAODV routing protocol. By using fresh sequence number, it is able to avoid any kind of formation of loop. It is more scalable than other mesh based protocols. However, it shows poor performance under node mobility scenario. Moreover, after link repair, it does not assure shortest path from all the nodes to the group leader.

In recent years, several researchers carried out their study on MAODV and proposed several extensions. For instance, in the research paper [31], the author extends performance of AODV and MAODV by using link state prediction method. The method can predict the exact link breakage time of an active link before the breakage actually occurs. In [32], the authors proposed a new application called name directory, which can be categorized as peer-to-peer application in MANET. Through that name service, which announces the information of neighbors, ad hoc users will be able to know who is reachable in the network. Multiple Tree Multicast Ad Hoc On-demand Distance Vector (MT-MAODV) routing protocol, an extension of MAODV protocol, is proposed by Chee-Onn and Hiroshi [33]. In this paper, authors attempt to improve video multicast over ad hoc network by using multiple tree concept. Two optimally disjoint trees are constructed employing a single routine. Authors of paper [34], deal with this issue of QoS. Their solution of QoS multicast routing problem is based on lower layer specifics and implemented on MAODV. In paper [35], a novel link enhancement mechanism is proposed to deal with mobility management problem in vehicular ad hoc networks. To enhance the link break prediction accuracy and congestion occurrence two machine learning techniques, particle swarm optimization and fuzzy logic systems, are incorporated into the proposed schemes. This technique is implemented in both AODV and multicast extension of AODV (MAODV) and experimental results supports the effectiveness and feasibility of the proposed schemes. Modified Shared-tree Multicast Routing Protocol (MSMRP) and modified shared-tree multicast routing protocol extension (MSMRPx) [36], are based on MAODV. The primary intent behind MSMRP is to improve the end-to-end delay in the shared-tree method. It uses n-hop local ring search to establish a new forwarding path and limit the flooding region. Authors also propose an extension by using the periodic route discovery message to improve the network throughput for the high mobility networks.

2.3 Multicast Open Shortest Path First (MOSPF)

MOSPF protocol is a multicast enhancement of OSPFv2 [37] protocol to provide efficient multicasting within an autonomous system. Routers in MOSPF maintain a current image of the whole network topology through the unicast OSPF protocol. This is achieved by periodic broadcast of a new type of *link state advertisement (LSA)*, also known as the *group-membership-LSA*. It then allows routers to build efficient source-based trees or a shortest-path tree using link-state information and Dijkstra's algorithm [38]. These trees are constructed on demand basis without even flooding the first datagram of a group transmission and the results of the calculations are cached for use by subsequent packets. Multicast datagram, which are forwarded, travel the shortest path since a separate tree is built for each datagram's source and receiver group pair.

Using MOSPF, it is possible to get a faster network convergence than DVMRP. It also adjusts rapidly to availability of network resources or changes in group membership. However, the flooding of group membership information is the predominant factor that preventing MOSPF being applicable over the wide area networks. Another limiting factor is the computational cost. This protocol involves heavy computation at each router and requires a lot of exchange of topology and membership information. Another problem with MOSPF is that it does not have the ability to "tunnel" multicast datagrams through non-multicast routers.

In paper [39], an extension of MOSPF is proposed to achieve tunnel multicasting, which aims at reducing protocol overhead by exempting non-branching nodes from processing routing information. In [40], another extension for MOSPF is proposed to support multicast communications. The authors proposed a self-feedback mechanism controlled by an annealing strategy and embedded into the Hopfield neural network to calculate the shortest-path tree for MOSPF Protocol.

3. Simulation Environments and Performance Metrics

The overall goal of this simulation study is to evaluate and analyze the performance of three existing multicast routing protocols; they are: ODMRP, MAODV and MOSPF over Wireless Mesh Networks (WMNs) environment. The simulations have been performed using QualNet version 4.5 [45], a software that provides scalable simulations of Wireless Networks, which is a commercial version of GloMoSim [46]. The term "mesh point" and "wireless router" are used interchangeably throughout the discussion. The simulation modeled two networks, one network (small network) of 50 routers over a terrain of 1250m x 1250m area and another network (large network) of 100 routers over a terrain of 2500m x 2500m area. The routers are distributed uniformly within a terrain. All the routers are stationary and there is no network partitioning throughout the entire simulation. The data transmission rate (unicast and multicast) and data transmission rate for broadcast is 2Mbits/s. At physical layer PHY 802.11b and at MAC layer MAC 802.11s is used. Each experiment was performed for 600 seconds of simulation time. Multiple runs with different seed numbers are conducted for each scenario and collected data is averaged over those runs.

The main traffic source in the simulation is Multicast Constant Bit Rate (MCBR) traffic. Each multicast group has one sender and either 10 receivers or 20 receivers for small network and 20 receivers to 40 receivers for large network. The sender transmits multicast traffic at a rate from 10 to 60 packets/sec. The senders and receivers are chosen randomly among multicast members. A member joins the multicast session at the beginning of the simulation and remains as a member throughout the simulation. In the simulation, initial 10s is kept to perform this task. Once joining the multicast group, we let the source to transmit data for 550s simulation time and remaining 40s is set to allow the last packets to be processed and routed to the receiver. The background traffic source is implemented using unicast flows. Constant Bit Rate (CBR) and File Transfer Protocol (FTP) traffic are used, each sending at a rate of 1 packets/s. The packet size without header is 512 bytes. The length of the queue at every node is 50 Kbytes where all the packets are scheduled on a first-in-first-out (FIFO) basis. The parameters are summarized in Table 1.

To evaluate the performance of routing protocols, both qualitative and quantitative metrics are needed. Most of the routing protocols ensure the qualitative metrics. Therefore, three different quantitative metrics are used to compare the performance. They are,

1) *Packet Delivery Ratio (PDR):* The ratio of the number of data packets received by the receivers verses the number of data packets supposed to be received. This number presents the effectiveness of a protocol [47].

2) *Average End-to-end delay:* End-to-end delay indicates how long it took for a packet to travel from the source to the receiver.

3) *Throughput:* The throughput is defined as the total amount of data a receiver actually receives from the sender divided by the time between receiving the fast packet and last packet.

Table 1: Summary of Simulation Environments

Parameters	Value
Network size	50 nodes over 1250m x 1250m area (small) 100 nodes over 2500m x 2500m area (large)
Path loss model	Two-ray propagation model
Transmission rate at PHY	2 Mbits/s
Physical layer protocol	PHY802.11b
Data link layer protocol	MAC802.11s
Queue size at router	50KB
Queuing policy at router	First-in-First-out
Multicast group size	{10, 20} nodes (small network) {20, 40} nodes (large network)
Traffic model of Sources	Multicast Constant Bit Rate (MCBR)
Number of source	1
Multicast Traffic Flow	{10, 20, 30, 40, 50, 60} pkts/sec
Back Ground Traffic Flow	Constant Bit Rate (CBR) & FTP traffic
Number of Unicast Source	5
Background Traffic Rate	1 packets/sec
Duration of Experiment	600 sec
Data Transmission Start	10 sec
Data Transmission Stop	550 sec
Number of Runs	10
Multicast Routing Protocols	ODMRP, MAODV, MOSPF

4. Results and Discussions

In this section, the performance of ODMRP, MAODV, and MOSPF are investigated and analyzed based on the results obtained from the simulation. A number of experiments are performed to explore the performance of these protocols with respect to a number of parameters such as multicast traffic load. Simulations are performed by varying multicast group size and using multicast traffic load parameter. For large network, group size of 20 and 40 receivers are considered, whereas for small network, group size of 10 and 20 receivers are considered.

In case of Multicast PDR, described in Fig. 1 for large networks and Fig. 2 for small networks, it is observed that all protocols performance is affected by the increasing network traffic. Increased network traffic results in packet loss due to buffer overflow and congestion. For all kinds of traffic load, ODMRP outperforms other two protocols. ODMRP uses a subset of nodes, or forwarding group, to forward packets to receiver via scoped flooding. This path redundancy enables ODMRP to suffer only minimal data loss. As MAODV and MOSPF are tree-based routing protocols and use only one path to send data from sender to the receivers, their packet loss ratio is higher. Among the other two protocols, MAODV performs better than MOSPF.

Fig. 3 and Fig. 4 illustrate the average end-to-end delay of large and small networks respectively. The average end-to-end delay incurred by MOSPF is the lowest in almost all cases. MOSPF uses Shortest Path Trees (SPTs) algorithm. The goal of SPT algorithms is to construct a tree rooted at the sender and spanning all the receivers such that the distance between the sender and each receiver along the tree in minimum (Nguyen, 2008). The average end-to-end delay of mesh based ODMRP is higher than MOSPF but much lower than MAODV. Since MAODV uses bi-directional multicast tree which is shared by all the members of the group, a packet needs to travel longer path than other two techniques, hence end-to-end delay is higher in all the scenarios.

The average throughput of Large and Small networks is given in Fig. 5 and Fig. 6 respectively. According to the figures, the average throughput of ODMRP is higher than MAODV and MOSPF in all simulation scenarios. ODMRP has better packet delivery ratio as well as higher throughput. Since ODMRP maintains meshes, it has multiple redundant paths to receivers. MAODV shows poor performance than ODMRP with respect to throughput parameter. This happens because a packet in MAODV needs to travel longer average path lengths. The longer the path a packet has to travel, the higher its chance of getting damaged or lost due to collision and/or congestion. MOSPF performs worse than the other two protocols in terms of throughput. Though average end-to-end delay of MOSPF is the lowest and its packets do not need to travel longer path, but for huge number of control packets exchange, its throughput and packet delivery ratio is less than other two protocols.

5. Conclusion

In this paper, analysis and investigations are carried out on the acquired simulation results of three prominent multicast routing protocols, ODMRP, MAODV and MOSPF. All the simulations are performed over wireless mesh networks. MOSPF is selected as the representative of proactive multicast routing protocols. On the other hand, MAODV is selected as the representative of tree-based and ODMRP as the representative of mesh-based multicast routing protocols. Both MAODV and ODMRP are reactive multicast routing protocols. From the investigation, it can be concluded that proactive multicast routing protocols are not suitable for WMNs, because of their huge routing overheads. Among the other two reactive routing protocols, mesh based (ODMRP) shows better performance than tree based (MAODV) routing protocol.

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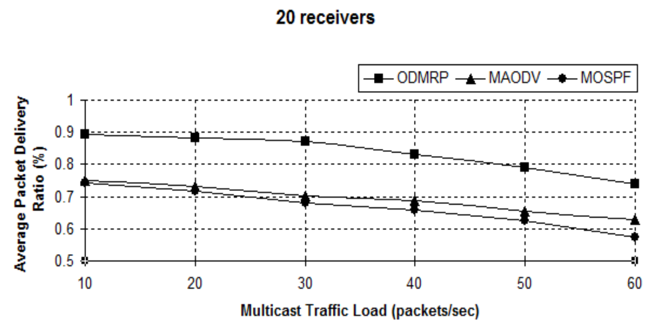
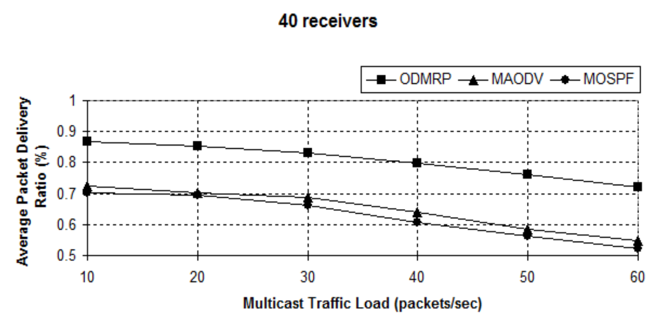
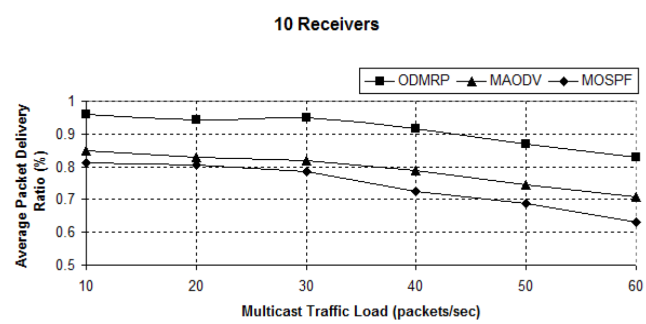


(a)

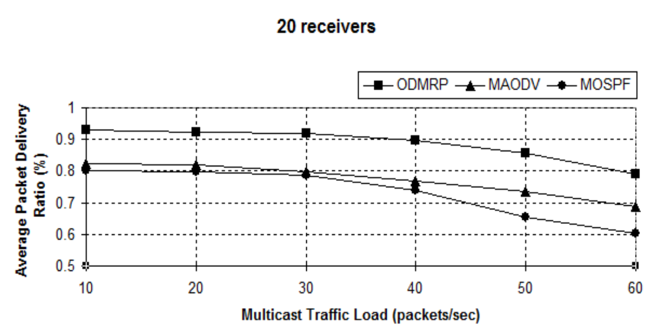


(b)

Fig. 1 Multicast PDR in Large Network

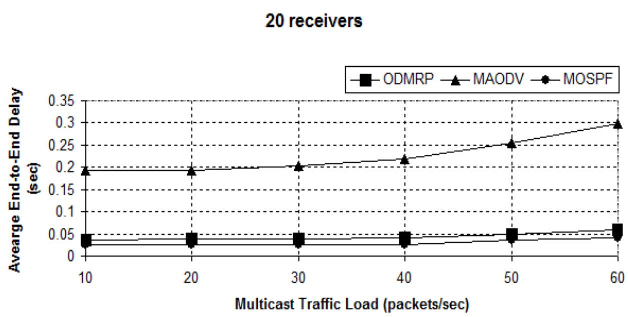


(a)

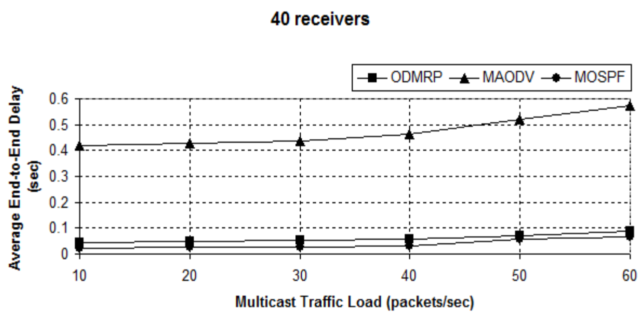


(b)

Fig. 2 Multicast PDR in Small Network

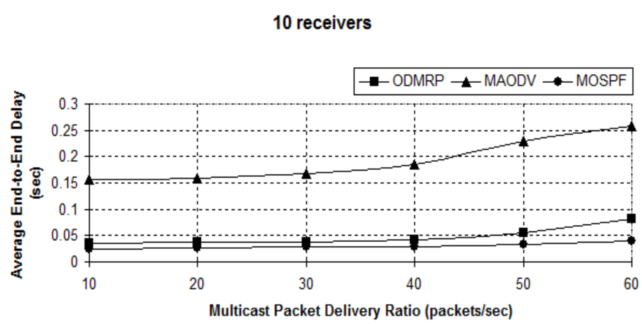


(a)

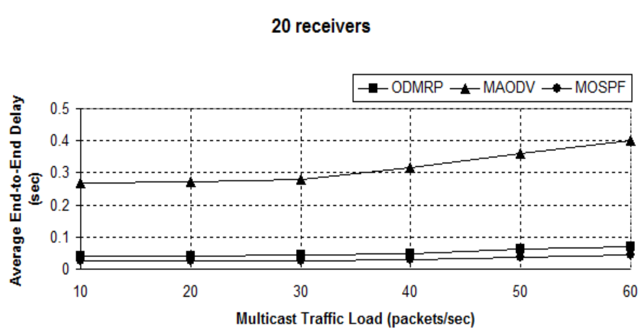


(b)

Fig. 3 Average End-to-End Delay in Large Network

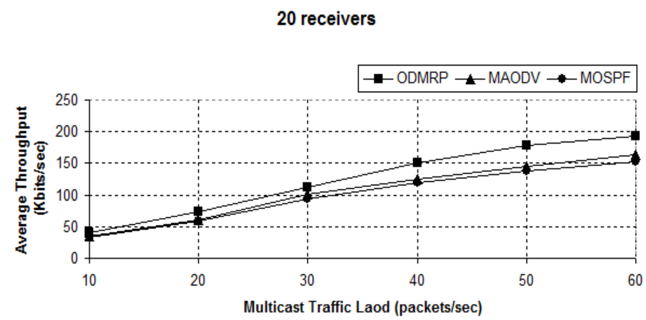


(a)

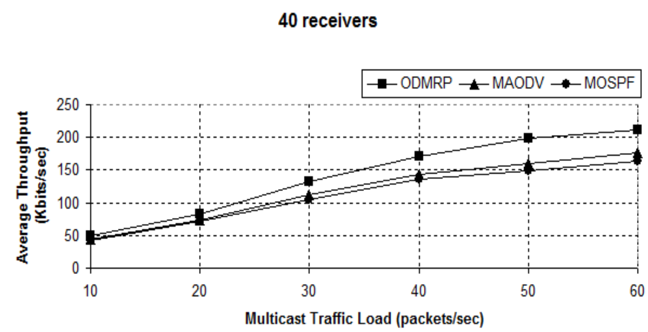


(b)

Fig. 4 Average End-to-End Delay in Small Network

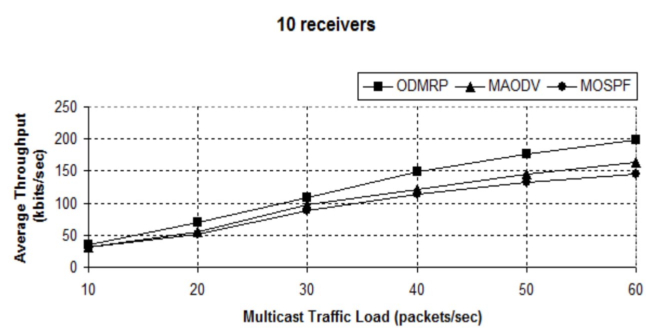


(a)

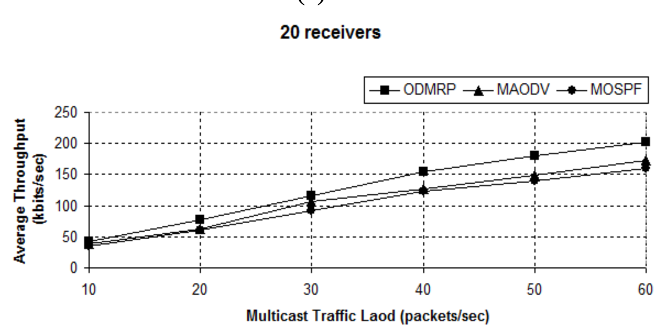


(b)

Fig. 5 Average Throughput in Large Network



(a)



(b)

Fig. 6 Average Throughput for Small Network