AVOIDING CONGESTED NODES IN MULTICAST ROUTING PROTOCOLS

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DEDICATION

To Islam,
the greatest religion that gives us the motive to work and achieve

To my dear brother Mohammed,
For his support, patience, and encouragement through my life

To all those who gave me the support,

I dedicate this work.

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LIST OF ABBREVIATIONS

ACK	Acknowledgement
ADMR	Adaptive Demand-Driven Multicast Routing
AG	Anonymous Gossip
AIQL	Aggregate Interface Queue Length
AMRIS	Ad hoc Multicast Routing protocol utilizing Increasing id-numberS
AODV	Ad hoc On-demand Distance Vector
ARQ	Automatic Retransmission Request -based,
CAMP	Core-Assisted Mesh Protocol
CBR	Constant Bit Rate
CCAG	Congestion Controlled Anonymous Gossip
CEDAR	Core-Extraction Distributed Ad Hoc Routing
CGSR	Clusterhead Gateway Switch Routing
DLAR	Dynamic Load-Aware Routing
Dest-Addr	Destination Address
Dest-Seq#	Destination Sequence Number
DSDV	Destination Sequence Distance Vector routing protocol
DSR	Dynamic Source Routing
FEC	Forward Error Correction-based
FSR	Fisheye State Routing
GL	Group Leader
GLBM	Gateway-cluster based Load Balancing Multicast algorithm
GRPH	Group Hello

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HARP	Hybrid Ad hoc Routing Protocol
Hop-Cnt	Hop Count
HSR	Hierarchical State Routing
IEEE	Institute of Electrical and Electronics Engineers
IFQ	Interface Queue
IP	Internet Protocol
J-Flag	Join Flag
LANMAR	Landmark Ad hoc Routing
MAC	Medium Access Control
MACT	Multicast Route Activation
MANET	Mobile Ad Hoc Network
MAODV	Multicast Ad hoc On-Demand Distance Vector
Mgroup-Hop	Multicast Group Hop Count
NS	Network Simulator
OTCL	Object-oriented Tool Command Language
ODMRP	On-Demand Multicast Routing Protocol
PDR	Packet Delivery Ratio
QoS	Quality of Service
R-Flag	Repair Flag
RALM	Reliable Adaptive Light Weight Multicast Transport Protocol
ReACT	Rliable, Adaptive Congestion-Controlled Adhoc Multicast Transport Protocol
RMA	Reliable Multicast Algorithm

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RREP	Route Reply
RREQ	Route Request
TCP	Transmission Control Protocol
TORA	Temporally Ordered Routing Algorithm
TTL	Time To Live
U-Flag	Update Flag
WMN	Wireless Mesh Network
ZRP	Zone Routing Protocol

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AVOIDING CONGESTED NODES IN MULTICAST ROUTING PROTOCOLS

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ABSTRACT

Mobile Ad Hoc Networks (MANETs) attract many researchers in the world because they are used in the areas where wired networks are not available. The limitations of MANET make the development of multicast routing protocols more difficult than that for wired networks. Multicast routing protocols are classified into proactive and reactive according to the route state information. They are also classified to tree-based or mesh-based according to the data structure used to transmit the multicast packets.

The most popular multicast protocol in MANET is Multicast Ad-Hoc On Demand Distance Vector (MAODV). The MAODV is a tree-based routing protocol that requests a route only on-demand. The MAODV uses the minimum hop count metric to find possible route between the source and the destination. However, finding shortest path is not always the right choice especially in a high loaded network. That's because the protocol does not ensure packet delivery in addition to the high possibility of congestion and delays. This thesis proposed a new multicast protocol which uses the Interface Queue Length (IFQ-Length) as a primary metric to select the least loaded path in high traffic networks instead of minimum hop count metric. The new protocol is called Load Balancing (LB-MAODV). The LB-MAODV protocol creates a Minimum Congested Tree instead of Minimum Hop Tree.

The performances of the LB-MAODV protocol are investigated through the Network Simulator (NS-2) and compared with the MAODV protocol. The simulation results show that LB-MAODV improves multicast communications in high traffic networks. The average improvement of Packet Delivery Ratio (PDR) is 3% and the average improvement ratio of end-to-end delay is 4% respectively. An average of 3.5% performance enhancement was achieved.

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1. Introduction

1.1 Overview

An Ad Hoc network is a set of mobile nodes established dynamically without any central management. Mobile Ad Hoc Networks (MANETs) attract many researchers in the world because they are used in the areas where wired networks are not available, such as military applications, contingency search and rescue places, where fast spreading is needed (Junhai, et al., 2008).

The Ad Hoc On Demand Distance Vector Routing (AODV) protocol supports unicast, multicast and broadcast transmissions which gives more strength to the protocol because it allows nodes to collect both unicast and multicast information and makes coding more simple (Royer and Perkins, 1999).

Since power consumption and transmission overhead are big challenges to Ad Hoc networks. Multicasting is good solution to those challenges because it uses the broadcast feature in the wireless communication to transmit many counterparts from the message (Junhai, et al., 2008). Multicast is a kind of transmission that transfers packets from a source to a group of destinations at the same time using an effective strategy (Wu and Jia, 2007) (Nguyen, 2008).

Multicast routing protocols can be classified depending on two different ways. The first method keeps the route state information so it classifies the protocols into proactive and reactive. Proactive routing protocols save the route state but reactive protocols request the route only on demand. The second method refers to the data structure used to transmit the multicast packets; protocols can be tree-based or mesh-based (Viswanath, et al., 2006) (Liu, et al., 2008).

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Multicast Ad Hoc On-demand Distance Vector (MAODV) is a tree-based routing protocol that requests a route only on-demand. The MAODV follows the same procedures and uses the same Route Requests (RREQ) and Route Replies (RREP) messages that used in the unicast protocol AODV, with new messages the Multicast Activation (MACT), and the Group Hellos messages (GRPH) (Royer and Perkins, 1999).

Nodes start to discover paths by using the RREQ/RREP messages. When the source node needs a route to a multicast address, it broadcast a RREQ message. Only group leader (GL) and group members can send RREP message. Any node that does not belong to the tree rebroadcast the message again until it reaches to the required nodes. When nodes receive the RREQ messages they update there routing tables. They also register the sequence number and the next hop information to the node that creates the RREQ thus creating the reverse path. After the RREP unicasted back to the source node the forward path is created. The source node may receive several replies but it selects the reply with the freshest sequence number or the smallest hop count. Then the source node sends a MACT message to the node that sends the reply in order to activate the path between them. If the source node does not receive any reply after some retries (RREQ_RERTRIES), it will declare itself as a group leader. The group leader broadcast a GRPH message periodically to give information about that group. GRPH messages are very important to keep the group connected with each other (Viswanath, et al., 2006). More detailed information about MAODV is given in Chapter (2).

Ad Hoc networks have many challenges that restrict the development of multicast protocols. Some of these constraints are nodes movements, traffic load and congestion. They are considered as main challenges in wireless network (ONIFADE, et al., 2007).

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Most of the existing Ad Hoc protocols such as On-Demand Multicast Routing Protocol (ODMRP) (Lee, et al., 1999) and MAODV (Royer and Perkins, 1999) use the minimum hop count as a basic metric to select the path from source to destination. Finding a shortest path is not always the right choice especially in a high loaded network because those protocols do not ensure packet delivery when the network is highly loaded since there is a high possibility for congestion and increased delays.

This thesis takes the MAODV protocol as a case study for the shortest path protocols. The protocol was modified in order to enhance its performance in a high traffic network since minimum hop count is not the suitable choice in that situation.

1.2 Motivations and Objectives

The Ad Hoc networks are important to be used on those situations where wired networks are not available. MANET characteristics make packets loss and delay larger than wired network. Multicasting provides good solution to MANET challenges since it can send packets to a group of hosts. Many multicast routing protocols have been designed recently to meet Ad Hoc network requirements, such as ODMRP which is mesh-based protocol and MADOV as tree-based protocol but none of these are reliable.

Congestion occurs when router receives data packets more than what it can handle. Hence, it starts to drop packets since the queue is full. The problem of congestion and packet loss are discussed in many papers (Chandra, et al., 2001) (ONIFADE, et al., 2007) (Onifade, et. al, 2008) those papers concentrate on protocols reliability in Ad Hoc networks. None of those papers discuss the ability to avoid congestion or to improve the performance of the MAODV protocol itself. Instead they focused on the recovery process.

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In (Zhao, et al., 2009) the authors address avoiding congestion problem on Wireless Mesh Network (WMN). The proposed protocol depends on the existence of gateway to administrate the operations. Ad hoc protocols such as MAODV which is a tree-based protocol do not have central control because each node acts as a router and a host at the same time, there is no single point of failure in the network.

The main goal of this thesis is to enhance the MAODV protocol to avoid congestion in a high traffic network by proposing Load-Balancing Multicast Ad Hoc On Demand Distance Vector (LB-MAODV) protocol. The new enhancement considers the number of packets lined up in the interface queue in each node exists in the route between source and destination as a primary route metric selection. The interface queue buffers all the incoming and outgoing packets of a node. The thesis adopts MAODV protocol because it’s popular and widely accepted.

This thesis provides the following contributions:

1. Introducing the proposed LB-MAODV protocol which uses the Interface Queue length (IFQ length) to select the least loaded route between source and destination, instead of the minimum hop count selection metric.
2. Studying the performance of LB-MAODV protocol and comparing it with the MAODV routing protocol.
3. Analyzing and comparing the obtained results.
4. Drawing a conclusion.

1.3 Organization of the Thesis

This thesis starts with an introduction about the definition of MANET, multicasting and MAODV routing protocol. Chapter (2) describes the topics mentioned in the

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introduction in more details. It talks about unicast and multicast routing protocols proposed for MANET in addition it talks about the load balancing and related work. Chapter (3) describes the LB-MAODV protocol and provides an example to explain it. Chapter (4) describes system specifications and the evaluation metrics that have been used in this thesis. Chapter (5) describes the simulation experiments of LB-MAODV and discusses the obtained results in details. The conclusion and future work are summarized in chapter (6).

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2. Background and Related Work

2.1 Overview

A Mobile Ad Hoc Network (MANET) is set of nodes that communicate with each other without any need to central control. They are dynamically connected to each other. The mobile nodes exist in environment where fixed network infrastructure does not exist. Each node acts as a router and a host simultaneously. Nodes can transmit packets among them when they exist in the same transmission range. Otherwise, they depend on there neighbors to transmit packets (Chlamtac, et al, 2003).

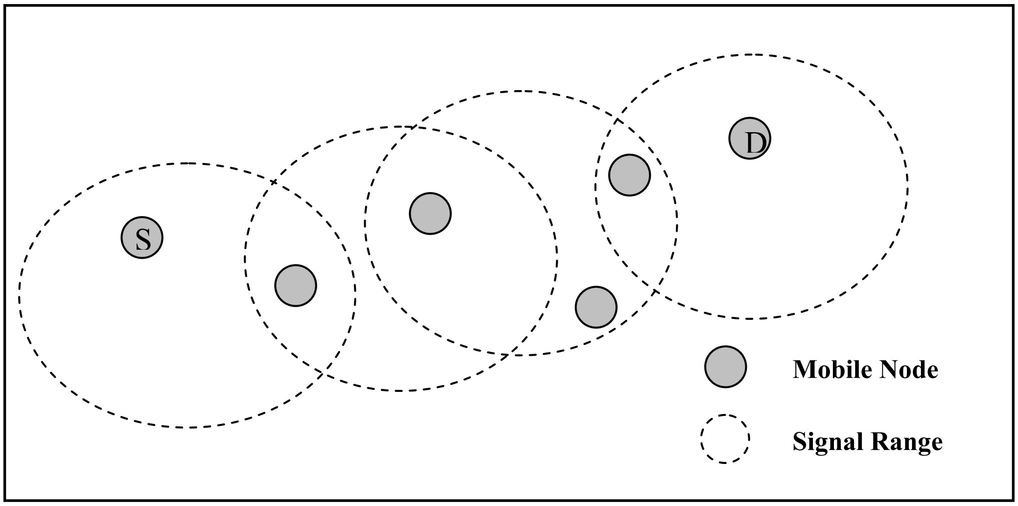

Figure 2.1 Each node represents a host and router

The ad hoc networks are very useful in the situations where the existence of wired networks are very difficult even impossible such as recovering from disaster, controlling throngs, sensor networks, seek and military applications. The nodes in mobile ad hoc network move frequently. Hence, the network topology is not stable. Since we are talking about mobile nodes, the bandwidth and battery power are very limited. Those limitations make designing routing protocols for MANET extremely difficult (Junhai, et al., 2008).

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Routing is a method to interchange data between nodes in the network. Routing in the network can be classified into unicast, broadcast and multicast. Unicast is point-to-point transmission. Broadcast is the transmission of data to all nodes in the network. Multicast is the transmission of data to a groups of nodes in the network.

2.2 Unicast Routing Protocols

Unicast is the mechanism of sending data from one sender to one receiver. Many of the classification methods, such as reactive and proactive routing protocols, that used for unicast are also used for multicast protocols. Unicast protocols are classified into uniform routing and non-uniform routing (Liu and Kaiser, 2003).

2.2.1 Uniform Routing Protocols

In uniform routing protocols all nodes are the same. There is no special node that has priorities over other nodes such as control or management. Uniform routing is classified into Proactive routing protocols, such as Destination Sequence Distance Vector routing protocol (DSDV) (Perkins and Bhagwat, 1994) and Fisheye State Routing (FSR) (Pei, et al., 2000). Reactive routing protocols such as Temporally Ordered Routing Algorithm (TORA) (Park and Corson, 1997)[A] (Park and Corson, 1997)[B], Dynamic Source Routing Protocol (DSR) (Johnson and Maltz, 1996) and Ad Hoc On-demand Distance Vector Routing protocol (AODV) (Royer and Perkins, 1999).

2.2.2 Non-uniform Routing Protocols

Non-uniform routing protocols belong to the hierarchical network structures to improve node administration and organization. Some nodes in these protocols have the

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control over other nodes. Non-uniform routing protocols are classified into Zone-based routing, Cluster-based routing and Core-node based routing (Liu and Kaiser, 2003).

In zone-based routing, nodes are organized by different zone constructing algorithms. Some examples on this approach are: Zone Routing Protocol (ZRP) (Haas, 1997) (Haas and Pearlman, 1998) and Hybrid Ad hoc Routing Protocol (HARP) (Nikaein, et al., 2001). In cluster-based routing there are clusters of nodes and clusterheads. Clusterheads are responsible for management. Some of these protocols are: Clusterhead Gateway Switch Routing (CGSR) (Chiang, et al., 1997) and Hierarchical State Routing (HSR) (Iwata, et al., 1999). In Core-node based routing protocols there are special nodes selected to carry out a special functions. Some different examples on these protocols are: Landmark Ad hoc Routing (LANMAR) (Pei, et al., 2000) and Core-Extraction Distributed Ad Hoc Routing (CEDAR) (Sinha, et al., 1999).

2.3 Multicast Routing Protocols Proposed for MANET

Multicast is a kind of transmission that transfer packets from a source to a group of destinations at the same time, using an effective strategy (Wu and Jia, 2007) (Nguyen, 2008). Routing protocols can be classified into two types proactive and reactive according to maintain the topological information about the network and to tree-based or mesh-based according to the data structure used to transmit the data packets (Viswanath, et al., 2006).

2.3.1 Proactive Routing Protocols

Each node in the network keeps tables that provide information about the network topology. Those protocols are called “table-driven”. The tables are changed recurrently to keep up-to-date routing information about other nodes in the network. This requires

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transmitting information among nodes thus increasing the overhead in the network. But this will reduce delay because routes always ready when the request needed (Junhai, et al., 2008). Some examples of proactive multicast routing protocols are Core-Assisted Mesh Protocol (CAMP) and Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) (Ji and Corson, 1998) (Wu, et al., 1998).

2.3.2 Reactive Routing Protocols

In this approach nodes create routes only "on-demand" when they need to communicate with other nodes that they do not keep route about. Reactive routing protocols are more scalable than proactive routing protocols. In addition, there will be a little delay before sending packets because they have to find a suitable route (Junhai, et al., 2008). ODMRP and MAODV are examples for reactive multicast routing protocols (Lee, et al., 1999) (Royer and Perkins, 1999).

2.3.3 Mesh-Based Protocols

In Mesh-based protocols the mesh nodes use flooding strategy in forwarding. The ODMRP is an example of mesh-based protocols. When a node has multicast data to send, it piggybacks the data in the Join Query Packet then sends it to all neighbors. The reverse path is constructed by saving the information, that were sent from the upstream nodes, in the routing table. The node then rebroadcast the query. The operation continues until the query reaches to a group member. The multicast receiver then creates the join table packet which contains some information such as the multicast group address. The node then broadcast the join table. Any node receives the join table will compare the address in its route table with the next node address exists in the join table. If the address exists in the

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table the node understands that it becomes part of the path and sets the forwarding group flag then broadcast its own join table. The operation continues to construct the forwarding group.

The mesh-based protocols cause more overhead than tree-based. They also suffer from lower scalability but higher guarantee of delivering data packets because there are multiple paths between the source and the receivers on the other hand, this might cause looping (Liu, et al., 2008) (Viswanath, et al., 2006).

2.3.4 Tree-Based Protocols

The multicast tree is composed of tree members; the group members and routers. The routers are the nodes between the group members. The first node who builds the tree is the Group Leader (GL). The MAODV protocol is an example for tree-based protocols and it is an extension for AODV that supports multicast communication (Royer and Perkins, 1999). The following sections will specify the protocol in details.

2.3.4.1 MAODV Description

2.3.4.1.1 MAODV Routing Tables

Each node in the Ad Hoc network may keep three tables. The first one is the Route Table. It is called unicast table. This table contains the following fields: the IP address of the destination, the sequence number of the destination, the hop count to the destination, the next hop and the life time. The RREQs and RREPs can not be received twice (Royer and Perkins, 1999).

The second table is the Multicast Table. Only tree members have this table. A tree member might be a group member or a router in the multicast tree. The table contains the

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following fields: the multicast group IP address, the multicast group leader IP address, the multicast group sequence number, the hop count to the multicast group leader, the next hops and finally the life time. In the multicast route entries, maybe more than one next hop are exist. Each next hop associated with an enabled flag. The enabled flag is set only when the route is accepted in the tree. The Multicast Activation message (MACT) is an indication that the path is added to the multicast tree.

The last table is the Request Table which contains the following fields: the multicast group IP address and the requesting node IP address. Each node in the network may have this table, weather it was a tree member or not. When a node receives RREQ to join the group it examines the request table to determine if there is an entry to the requesting node. If not the node who receives the RREQ adds the IP address of the requesting node and the multicast group address because the first node sends the RREQ becomes the group leader. Hence, if the current node decides latter to join the group, it can check the request table to send a join RREQ unicastly to the group leader (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

2.3.4.1.2 MAODV Route Discovery

Multicast Ad Hoc On-Demand Distance Vector is a reactive protocol which means that it sends a request only on-demand to detect a route to the destination. Some of the RREQ parameters are shown in Figure (2.2).

J-Flag	R-Flag	Broadcast-ID	Source-Addr
Source-Seq#	Dest-Addr	Dest-Seq#	Hop –Cnt

Figure 2.2 RREQ fields

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The join flag (J-Flag) is set when a non tree member wants to join the group. The repair flag (R-Flag) is set when the node detects a tree partition. Thus it creates a unicast request to merge the tree. The sequence number is used to determine the recentness of the route. Each RREQ is identified by combining the Broadcast-ID and the sequence number.

The source node broadcast the RREQ. Any node receives the RREQ from the source node updates the route table. If this node is the destination or if it has a route to the destination with a sequence number equal or greater than the sequence number included in the RREQ packet. Then the node sends a RREP to the requesting node and creates the forward path to the destination. Otherwise, the node rebroadcast the request after incrementing the hop count by one. It also creates the reverse route to the requesting node by adding the sequence number and the next hop to the source node in the route table.

The RREP packet is sent unicastly to the source node through the next hop. Some of the RREP parameters are shown in Figure (2.3).

J-Flag	R-Flag	Dest-Addr
Dest-Seq#	Hop-Cnt	Lifetime

Figure 2.3 RREP fields

The Dest-Addr is set to the destination address included in the RREQ packet. The Dest-Seq# is set to value registered about the destination in the node that sent the RREP. The hop count is set to zero if the responding node is the destination itself. Or it is set to the distance between the current node and the destination if the node that sends the RREP is not the destination.

Each node that receives the RREP increments the hop count by one and updates the route table to contain an entry to the destination node in order to create the forward route.

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The node then unicast the RREP to the next hop. The process continues until the RREP reaches to the source node. If the route does not activated before ACTIVE-ROUTE-TIME-OUT the intermediate nodes delete this route. The RREP in the source node and the intermediate nodes is updated only if they receive other RREPs that contain greater destination sequence or the same sequence number but smaller hop count.

Each node keeps local connectivity information about its neighbors. A node hears the packet transmission of its neighbors then updates the route table. If the node does not send packets within HELLO-INTERVAL milliseconds, it broadcast a hello message that contains node IP address and sequence number to indicate the existence of that node. The time to live (TTL) in the hello message is set to one to ensure that only neighbors receive the message (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

2.3.4.1.3 MAODV Route Request

Any node in the network that wants to join the multicast group or has data to be sent to a multicast group, the node sends a RREQ message. The node sets Dest-Addr to IP address of the multicast group and the Dest-Seq# to the last known sequence number for that group. The join flag (J-Flag) is set only if the request is to join the group. The node then broadcast the RREQ to all nodes in the network or unicast it to the group leader if there is enough information in the request table about that group. Only group members can respond to the join RREQ by sending RREP. But if the request is not join RREQ then any node with fresh enough route “has sequence number equal or greater than the one included in the RREQ” can respond. If the node which receives the join RREQ is not able to respond, it registers the group address with the requesting node IP address in the request table only if this is the first time it receives the request. This is because the requesting node

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may become a group leader latter. There for, the node can use the information in the request table if it decides latter to join the group. Then it rebroadcast the request. The reverse route to the requesting node is created in the unicast route table. The enabled flag to the entry of the reverse route is set to FALSE. Latter on it is set to TRUE only if a MACT message is received. The process continues until the request reaches to the node which can responds with a RREP message.

If the source node does not receive RREP within certain period of time, it will broadcast another RREQ. It continues sending RREQs to get a valid reply up to RREQ-RETRIES. Then if it still does not receive any reply, the node will consider the multicast group unreachable because the network is partitioned or because the group is not existed. It identifies itself as a group leader and creates the group sequence number (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

2.3.4.1.4 MAODV Route Reply

Only multicast members and group leader can respond to the join RREQ. If the node able to send a join RREP it updates the multicast route table by adding the next hop towards the requesting node then creates a join RREP. The node then unicast the RREP to the requesting node using the Source-Addr included in the RREQ field. The RREP packet contains the following information, the sequence number of the multicast group, the IP address of the multicast group, the IP address of the group leader and the hop count to the tree (Mgroup-Hop). The Mgroup-Hop initialized to zero. Nodes in the path which receive the join RREP increment the Mgroup-Hop by one. They also update the multicast table and the unicast table to create the forward path and then forward the join RREP. The process

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continues until the RREP reaches to the requesting node (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

2.3.4.1.5 MAODV Generating Group Hello Messages

The group leader regularly broadcast a group hello message every GOUP-HELLO-INTERVEL milliseconds to introduce the group in the network. The group hello message contains the following fields: the group sequence number which is incremented by the group leader each time it creates group hello message. In addition, the hop count to group leader which is initialized to zero then incremented at each node when receiving the message to indicate the distance between the current node and the group leader. Also, the multicast group leader IP address. Finally, Time To Live (TTL) which is greater than the network diameter to make sure that all nodes in the network receive the message. When a non tree member node receives the group hello message, it checks the request table if no entry to the group is existed it updates the table. If the node is a tree member it updates the multicast table information: such as group sequence number, current group leader and the distance between the node and the group leader. The group hello message is very important in detecting Tree Merge (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

2.3.4.2 Multicast Tree Maintenance

Multicast tree maintenance is classified into three operations: the first one is selecting and activating the link to be added to the tree when a new node joins the group. The second one is pruning the tree when a node decides to leave the group. The third one is repairing broken links (Royer and Perkins, 1999).

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2.3.4.2.1 Multicast Route Activation

The source node broadcast a join RREQ to the multicast address. Usually a node receives more than one RREP because each multicast group member gets the request sends its own reply. The source node is allowed to accept only one path to the tree to avoid loops during the RTE-DISCOVERY-TIMEOUT millisecond which indicates the time the node is allowed to wait for the RREPs before selecting a valid reply. The node accepts other RREPs if and only if they are with greater sequence number or the same sequence number and smallest number of hops to the tree.

After the RTE-DISCOVERY-TIMEOUT period is finished, the node enables the next hop to the tree in the multicast table and validates the path by sending MACT message to the node that sent the RREP. Some of the MACT message parameters are shown in Figure (2.4)

Flags	Hop-cnt	Source-Addr	Source-seq#	Dest-Addr

Figure 2.4 MACT fields

The Prune Flag (P-Flag) and the Group Leader Flag (GL-Flag) are used to prune the node from the tree and to select new leader respectively. Each node in the path receives the MACT message enables the source node entry in the multicast route table. The group members who receive the MACT message do not forward the message any more. Non member nodes forward the MACT to the next hop and enable the route entries in the multicast route table. The operation continues until the source node that sent the RREP is reached. Nodes which do not receive a MACT message will delete the forward path (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

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2.3.4.2.2 Pruning

The node can leave the group at any time it decides to end its membership in the multicast group. If the node is a leaf node, it can prune itself from the tree through the MACT message by sets the P-Flag (Prune Flag) and then unicast the message to the only next hop it has to the multicast group. The node then deletes all information about the multicast group from the multicast table. The next node receives the MACT message deletes all entries about the node who prunes itself from the multicast table. Then if it becomes a leaf node and it is not member in the multicast group it prunes itself too. If the node is not a leaf node it simply prunes itself from the tree but continues working as a router in the tree (Zhu and Kunz, 2004).

2.3.4.2.3 Repairing Broken Links

The multicast group members should keep in touch during the life time of the group. But the mobility and route expiration time may cause a break in the multicast group tree links. The downstream nodes are responsible for maintaining link breakage. When the downstream node does not receive any packets from its neighbor during the time HELLO-INTERVAL * (1 + ALLOWED-HELLO-LOSS) milliseconds, it understands that there is a link breakage. The downstream node deletes that next node and sends a join RREQ that is different from the join RREQ which is sent by non tree members to the group because the request packet includes additional field. When the downstream node sends the join RREQ to repair the broken link it includes the number of hops between itself and the group leader to prevent its downstream nodes from responding to this request and to avoid the old path between itself and the tree. Only group members with fresh enough sequence number and smaller or equal hop count to group leader can respond to the request.

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If the node tries several times RREQ-RETRIES milliseconds and do not receive any reply it decides that the network is partitioned. In this situation a new group leader to the portioned part should be selected. If the node that detects the breakage is a group member it becomes the group leader to the portioned part of the tree. Otherwise, if this node has only one next hop it sends a MACT message with (P-Flag) to prune itself. The next hop node understands after receiving the MACT that there is a tree partition and the tree needs a group leader. If this node is a group member it becomes the new group leader, otherwise the node performs the previous procedure until a group member is reached to become the new tree group leader.

If the node who detects the breakage has more than one hop, it will not be able to delete itself. This node sends a MACT message with Group Leader Flag (GL-Flag) to the first next hop it has. If the next hop is a group member then it becomes a group leader. Otherwise, it performs the previous procedure again. When a new node becomes the group leader to the tree it broadcast Group Hello with Update Flag (U-Flag) set. This is an indication to the nodes that this is the new group leader. Therefore, the nodes have to update there multicast route table. If the upstream node detects the breakage it waits ROUT-EXPIRATION millisecond to receive a MACT message from its downstream node. If the node does not receive the message it will prune itself from the tree (Zhu and Kunz, 2004).

2.3.4.3 Reconnecting Partitioned Tree

After tree partition occurs, there are two group leaders in the tree. If the group member receives a Group Hello message from larger group leader but with the same

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multicast address, this member realizes that there is a partition and the tree needs to be connected. If the member belongs to the smallest group leader it unicast RREQ with Repair Flag (R-Flag) set and sends it to the smallest group leader. The smallest group leader gives the permission to connect by unicast RREP with (R-Flag) set when the node which detects the breakage receives the RREP from the smaller group leader it unicast RREQ to the larger group leader to connect the tree. After the largest group leader "the node with the largest IP address in the tree" receives the request. It increments the multicast sequence number of the group included in the packet by one; to create the new group sequence number after the merge then it unicast RREP to a source node who sent the request. The old group leader latter unicast a Group Hello with (U-flag) set to its neighbors, to let them know about the new changes (Royer and Perkins, 1999) (Zhu and Kunz, 2004).

Table (2.1) lists some of the MAODV parameters that have been named in this thesis (Zhu and Kunz, 2004).

Table 2.1 some of MAODV Simulation Parameters

Parameter	**Meaning**	**Value**
RREQ_RETRIES	The number of times the node can retransmit RREQ	3
RTE-DISCONERY-TIMEOUT	The amount of time the node waits to get RREP	0.5 second
HELLO_INTERVAL	The amount of time between each Hello message And the next one issued by nodes	1 second
GROUP_HELLO_INTERVAL	The amount of time between each Group Hello Message and the next issued by group leader	5 seconds

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2.4 Load Balancing

Load balancing concerns with turning work from the heavily loaded nodes to those lightly loaded nodes in the network to get more resource utilization and to avoid the congestion. This procedure guarantees fairness in the network because it makes sure that no jobs waits for processing in the present of idle nodes (Rani and Dave, 2007). Most of the existing routing protocols use the minimum hop count as a primary metric selection. But this route can not be always the optimal choice especially in high loaded network where congestion possible to happen. Congestion occurs when nodes receive data more than what it can handle which causes packet loss and long delays

2.5 Related Work

There are so many researches about multicast routing protocols for mobile Ad Hoc networks. Some of them were classified as on-demand routing protocols such as MAODV (Royer and Perkins, 1999) and ODMRP (Lee, et al., 1999). Other protocols classified as table-driven such as CAMP (Ji and Corson, 1998) and AMRIS (Wu, et al., 1998).

Some protocols were proposed to those applications that require reliability which means all data packets should be received by all multicast group members. In (Ouyang, et al., 2005) the authors compare the existing MANET reliable multicast protocols and classify them into three classes according to the used method to recover the lost packets. Automatic Retransmission Request (ARQ)-based, gossip-based and Forward Error Correction (FEC)-based.

In the ARQ-based class, the sources retransfer all lost packets until they reach to all receivers. So many protocols belong to this kind of recovery, Reliable Multicast Algorithm (RMA) (Gopalsamy et al., 2002), Reliable Adaptive Light Weight Multicast Transport

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Protocol (RALM) (Tang et al., 2002) and Rliable, Adaptive Congestion-Controlled Adhoc Multicast Transport Protocol (ReACT) (Rajendran et al., 2003). In RMA (Gopalsamy et al., 2002), the source should receive acknowledgement (ACK) message from all receivers. Otherwise, the source will start the recovery process and retransmits the packets. The recovery process continues till the source collects ACK from all receivers.

In the gossip-based class the multicast members transfer the multicast packets several times. So many protocols belong to this type such as Anonymous Gossip (AG) (Chandra, et al., 2001) . In AG (Chandra, et al., 2001), the paper shows the use of AG protocol using MAODV as underlying protocol. The MAODV used to send multicast data packets as a first step in the protocol. The second step occurs when loss is detected; the group member transfers a gossip message to the closest member neighbor to recover the lost packets. The gossip message contains the following fields: the Group Address, the Source Address which represents the address of the node who sent the gossip message. Also, the Lost Buffer which contains the sequence numbers of the expected lost messages. In addition, the Number Lost which represents the size of the lost buffer and the Expected Sequence Number of the next message that the source node of gossip message expects. Each node maintains two tables, the lost_table which contains the sequence number of the packets that the node expects them lost and the history_table which contains the received messages. By using those tables the node that receives the gossip message, compares the lost_table contents which is included in the lost buffer field in the gossip message with the content of its history table. Hence, if the node which has received the gossip message detects any lost then it sends a gossip reply contains the lost packets.

In (ONIFADE, et al., 2007) and Congestion Controlled Anonymous Gossip (CCAG) (Onifade, et al., 2008), the authors use the gossip protocol to provide reliability in

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multicasting through minimizing diverge in the number of received packets, minimizing congestion and guarantee recovering lost packets. When the source receives Negative Acknowledgment (NACK) from any multicast member, it enters the congestion control phase. When the source receives ACK from all receivers in the network, the source considers that the network is no longer congested and stops the congestion control phase.
The author in (Kunz, 2003) compared the performance of different unicast , broadcast and multicast routing protocols using the NS2 simulator. He studied the amount of delivered data packets and the latency performance metrics, to highlight the reliability issue in the routing protocols. Three different traffic loads were evaluated in the study. The parameters for the first traffic were 2 packets per second and each packet 256 bytes. The second traffic parameters were 4 packets per second and each packet 512 bytes. The last traffic parameters were 8 packets per second and each packet 1024 bytes. The author in this study introduced the first load only because the MANET was heavily congested on the other loads which reduced the protocols performance. He also compared three multicast routing protocols: the MAODV, ODMRP and Adaptive Demand-Driven Multicast Routing (ADMR). He concluded that the MAODV was the worst because the control overhead in high mobility scenarios of MAODV was the largest and the queue is likely overflow even in small number of multicast senders. Finally, the author studied the use of BCAST protocol and provided an enhancement by using NACK to recover the lost packets. The author in this study didn’t provide any enhancement on the MAODV protocol itself he just studied its performance and concluded that it was the worst among all the studied multicast protocols in his study.

In Dynamic Load-Aware Routing (DLAR) (Lee and Gerla, 2001), the study adopts the number of packets queued in the interface queue as a basic route selection. The method

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was applied on unicast protocols to balance the network load. The DLAR is on-demand routing protocol. The source node sends a ROUT REQUEST to detect a route. The request is broadcasted to the entire network. Each node receives the request in the path adds its load information which contain the number of packets lined up in the interface and then rebroadcast the request. The destination can receive duplicate ROUTE REQUESTS. Each request represents a path. The destination selects the least loaded path and sends a ROUTE REPLY to the source node. The study introduced three algorithms to select the least loaded route. The least sum of number of packets lined up in each path, the average number of packets lined up in each intermediate node along the route and selecting the route with the least number of congested intermediate nodes by using a specific threshold.

In addition to the previous study, (Rani and Dave, 2007) represent Aggregate Interface Queue Length (AIQL) as a new metric in AODV instead of minimum hop count to deal with load splitting. Select the least load route and reduce the congestion in high loaded network. In this protocol the source node floods the RREQ. Any node receives the RREQ rebroadcast it after adding the interface queue length. The destination selects the best route then unicast RREP to the source node.

In (Zhao, et al., 2009), the study represents anew multicast algorithm. A Gateway-cluster based Load Balancing Multicast algorithm (GLBM) was invented to improve the QoS in Wireless Mesh Networks (WMNs). The protocol is different from existing multicast algorithms such as MADOV and ODMRP because it performs routing through a gateway. The protocol uses the gateway and load balancing to get the required QoS in WMN. The gateway works as a director in the WMNs to control accessing the internet and balance the load in the network. When a node wants to join a group it broadcast a request with join flag set combined with the IP address of the gateway. Every node receives the request adds the

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number of the packets exist in its interface queue then rebroadcast it. When the gateway gets the requests it selects the path with the least load then sends a reply to the source node.

Finally, this thesis is different from the previous studies because it applies a new modification on MAODV routing protocol in order to improve its performance. The thesis aims to avoid congestion, unlike the studies that concentrated on recovering mechanisms such as (Chandra, et al., 2001) (ONIFADE, et al., 2007) (Onifade, et al., 2008) (Gopalsamy et al., 2002). The thesis applies the interface queue length as a basic metric selection on a multicast protocol unlike the studies that applied the strategy on unicast protocols (Lee and Gerla, 2001) (Rani and Dave, 2007). The new metric is applied on the MAODV routing protocol which is a tree-based and on-demand protocol. The MAODV is an Ad Hoc protocol where nodes communicate without any centralized control and there is no single point of failure unlike (Zhao, et al., 2009) study which was applied on mesh-based protocol that administrated by a gateway. In addition, each node in the network in the MAODV protocol is allowed to send multicast data packets, whereas only the sending gateway in (Zhao, et al., 2009) study is allowed to send multicast packets. The LB-MAODV protocol relies on the source node to select the best route and uses the information in the RREP packet whereas (Lee and Gerla, 2001) (Rani and Dave, 2007) (Zhao, et al., 2009) studies rely on the destination node and depend on the RREQ packet.

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3. LB-MAODV Load-Balancing Multicast Ad Hoc On Demand Distance Vector

3.1 The Proposed Idea

This thesis drives at using a new metric to select the suitable route in a high traffic network. The load balancing to each path is calculated to find the least loaded path “the path with minimum number of packets lined up in the interface queue” instead of finding the shortest path “the path with minimum number of hops”.

The proposed protocol aims to improve the performance of the Ad Hoc protocols in a high traffic network by transmitting the jobs from the busy nodes to the idlest nodes. This reduces the waiting time and enhances the communications between nodes.

The thesis performed by using the MAODV routing protocol as a case study. The protocol uses minimum hop count as basic selection route criteria. The multicast protocol modified to use the IFQ-Length as a basic route metric selection. Figure (3.1) shows the MAODV multicast tree with group leader (G).

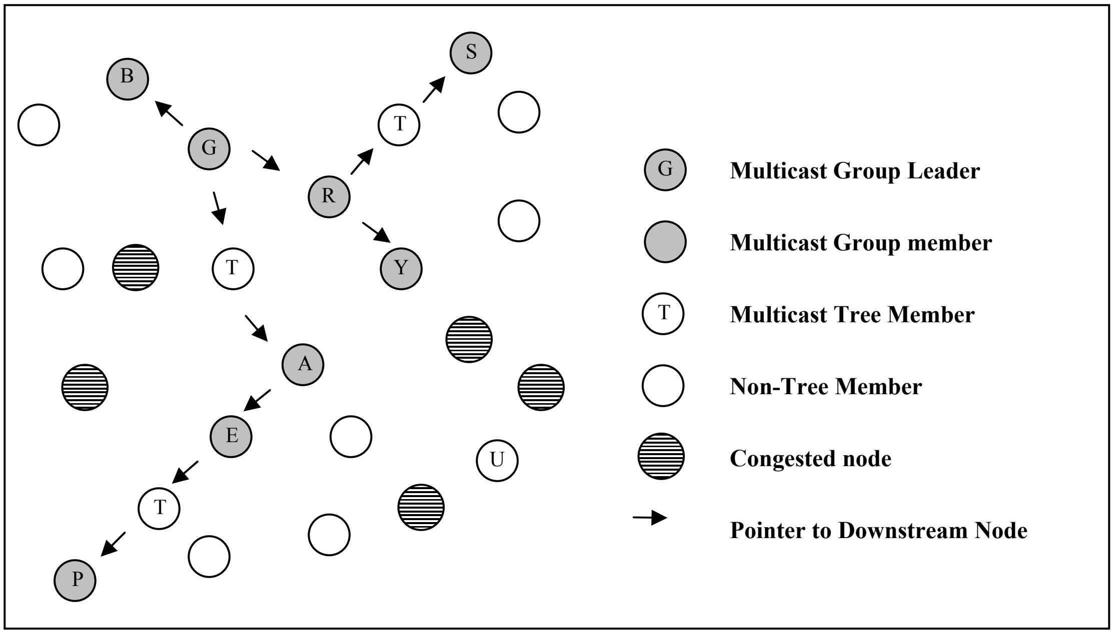

Figure 3.1 MAODV Multicast Tree

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3.2 Assumptions

The proposed approach has the following assumptions:

1. The approach is useful when the network is highly loaded.
2. Each node in the network is allowed to send multicast data packets then the multicast data packets is broadcasted to the multicast group members (Zhu and Kunz, 2004).
3. Only multicast data traffic exists in the network.
4. Every receiver is a multicast group member but each sender is not necessary to be a group member.
5. At the start of the simulation all receivers join a single multicast group then the senders begin sending data after (30) seconds (this is the appropriate time to the MAODV routing protocol to complete the tree construction) (Kunz, 2003) (Zhu and Kunz, 2004).
6. After (910) seconds all senders stop sending data (the senders stop the actual sending at 900 seconds, the remaining 10 seconds are used to give the packets that are still in flight a chance to be delivered) (Kunz, 2003) (Zhu and Kunz, 2004).

3.3 Protocol Details

Each node in the network wants to join a group broadcast a join RREQ. If non tree member node receives the join RREQ, it adds the multicast group address and the requesting node IP address in the Request Table because it may use it latter if it decides to join the group since the first node joins the group becomes the group leader. The node then updates the request packet by incrementing the hop count field and creates the reverse path to the source node then rebroadcast it. If a group member or a group leader receives the request, it responds by unicast the join RREP packet to the requesting node and creates the forward route.

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The RREP packet has been modified to include the Interface Queue Size (IFQ-Size) field which is initialized to zero and represents the route load towards the tree and the Interface queue Size Group Leader (IFQ-Size-Grp-Leader) field which is filled from the multicast table and represents the route load towards the group leader. The route load represents the sum of all packets lined up in the interface queue of each node lies in the route between the source node and the tree. The multicast route table has been modified to include the IFQ-Size-Grp-Leader field. Some of the RREP parameters in the LB-MAODV protocol can be seen in Figure 3.2.

R-Flag	U-Flag	Dest-Addr	Dest-Seq#
Hop-Cnt	Lifetime	IFQ-Size	IFQ-Size-Grp-Leader

Figure 3.2 LB-MAODV RREP fields

Each node receives the join RREP, increments one to the hop count and adds the IFQ-Length which represents the amount of packets in the interface queue of the node, to the stored values in the IFQ-Size and IFQ-Size-Grp-Leader fields. The node caches the information which is included in the RREP packet in the multicast route table then unicast the packet towards the requesting node. Each node is allowed to cache only one upstream node. If the node later receives a RREP indicating a better route with greater multicast sequence number or least IFQ-Length, it will accept that route and forwards the packet otherwise it will discard it.

The protocol at the beginning searches for the route that satisfy the minimum hop count and the least load conditions. If it doesn’t find that route it looks for the least loaded route and if all of them are the same it selects the minimum hop route (this situation occurs when the load in all the routes are the same so there is no different between the shortest

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route and the least loaded route). The protocol uses the Interface Queue Length as a primary metric and the minimum hop count as a secondary metric to select the routes. This is because the thesis aims to build the minimum congested tree. The source node waits RREP_WAIT_TIME milliseconds, before accepting the cached RREP, if it receives one. The accepted RREP by the source node usually represents the route with the least value of total queue length thus the packets will be transferred using the least loaded path instead of the highly loaded path.

The source node sends the MACT message with (J-Flag) to activate the selected branch between it and the tree. Some of the MACT parameters in the LB-MAODV protocol can be seen in Figure 3.3.

Flags	Hop-Cnt-Grp-Leader	Source-Addr
Source-Seq#	Dest-Addr	Ifq_Size_Grp_Leader

Figure 3.3 LB-MAODV MACT fields

Each node in the path receives the MACT message, stores the cached information in the multicast table and stores the upstream node from where it receives the join RREP and the downstream node from where it receives the MACT message with (J-flag). See the Figures (3.4), (3.5) and (3.6) for more details.

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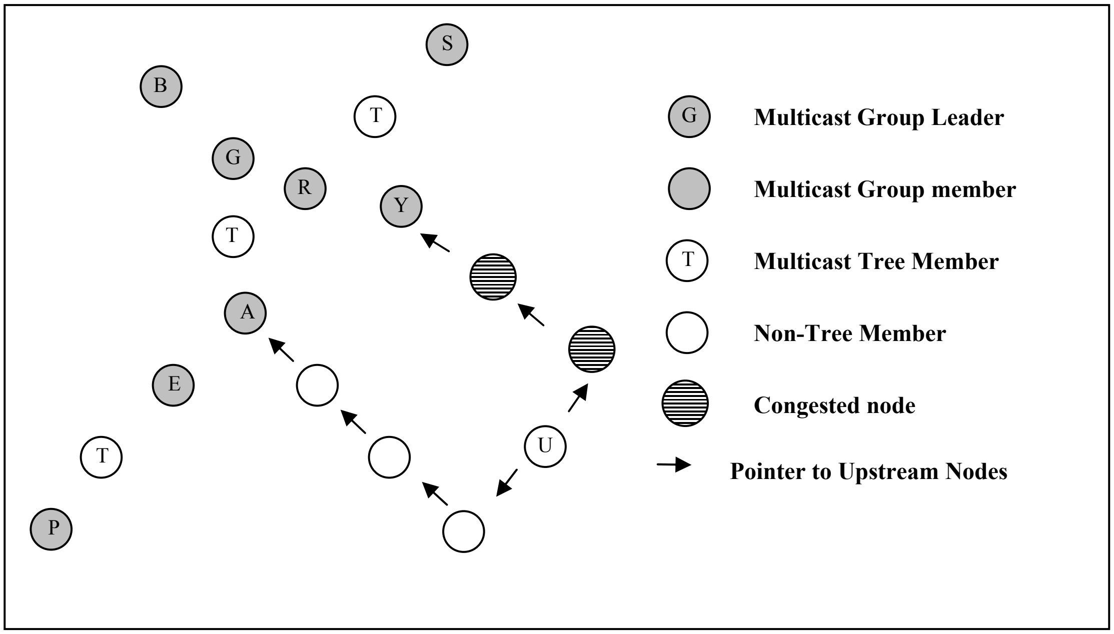

Figure 3.4 Node U Broadcast Join RREQ

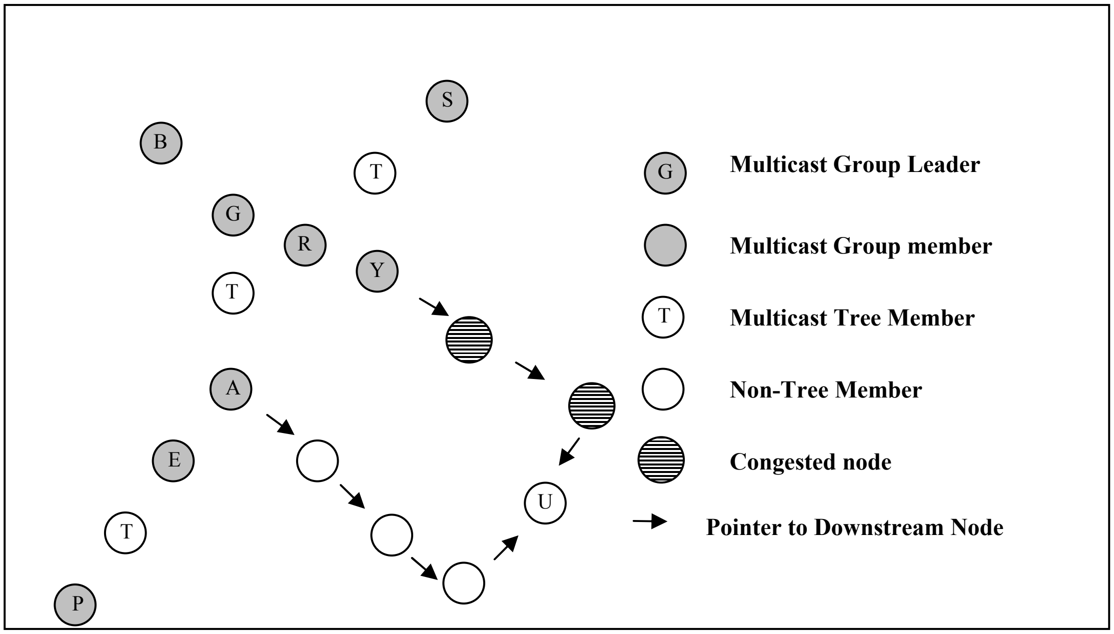

Figure 3.5 Node U Receives Join RREPs from Multicast Members

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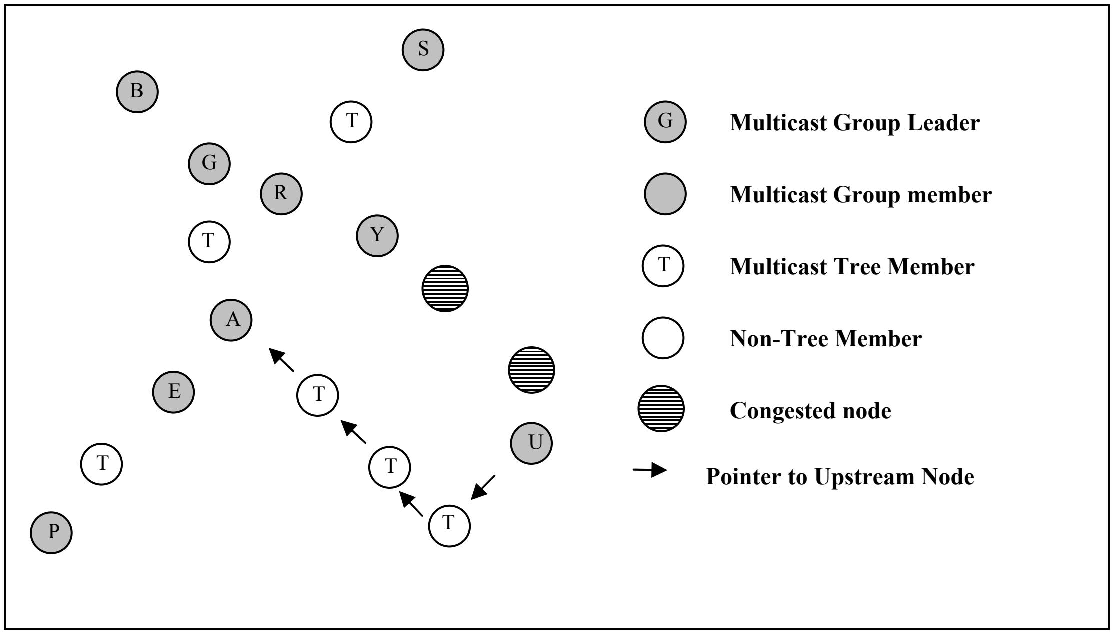

Figure 3.6 Node U activates the least loaded route by unicast MACT message

In the case of neighbor connectivity maintenance when a tree member detects a broken link it broadcast a join RREQ. This RREQ is different from the one which is sent by the non tree member because it includes the IFQ-Size-Grp-Leader field which represents the route load between the node and the group leader in addition to the hop count field between the node and the group leader. Those extension fields are used to avoid old branches and to prevent the current node downstream nodes from responding to this node request. Only group members with the least Interface Queue Length toward the group leader can respond. If the traffic is not high, the members with the least hop count toward the group leader can respond.

The group leader regularly broadcast the Group Hello message. The message has been modified to include the IFQ-Length towards the group leader. Some of the Group Hello parameters of modified protocol are shown in Figure (3.7).

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Grp-Seq#	Hop-Cnt-Grp-Leader	IFQ-Size-Grp-Leader
Group-IP-Addr	TTL	Grp-Leader-Addr

Figure 3.7 LB-MAODV GRP-HELLO fields

The IFQ-Size-Grp-Leader field in the Group Hello message is initialized to zero then incremented at each node receives the message to indicate the route load between current node and the group leader. Each tree member receives the Group Hello can use it to update its multicast table. If the node is non tree member then it adds the information in the request table if the message is never received before.

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```
Algorithm for LB-MAODV
/*MRQ-J: Multicast Request-Join*/
/*MRP-J: Multicast Reply-Join*/
/*GL: Group Leader*/
/*GM: Group Member*/
/* S: source node initialize MRQ-J*/
/*X: node receive the MRQ-J*/
/*F: node receive the MRP-J*/
/*N: number of queued up packets in the interface queue*/
STEP1:
 (1) Node (S) wants to send MRQ-J
      (1.1)  S checks the request table
      (1.2)  if multicast –address in the table UNICAST MRQ-J to GL
      (1.3)  else
      (1.4)  BROADCAST MRQ-J
      (1.5)  end if
STEP2:
(2) Node (X) receives MRQ-J
      (2.1)   if (X) is a (GL or GM) {
      (2.2)   Creates MRP-J
      (2.3)    IFQ-Size = 0
      (2.4)    if (x) = (GL) IFQ-Size-Grp-Leader = 0
      (2.5)    else
      (2.6)    IFQ-Size-Grp-Leader = IFQ-Size-Grp-Leader from Multicast Table
      (2.7)    end if
      (2.8)    UNICAST MRP-J to (S)}
      (2.9)    else
      (2.10)  REBROADCAST the MRQ-J
      (2.11)  end if
STEP3:
(3) Node (F) receives MRP-J
      (3.1)  if ( load info && hop info < cached info || load info < cached info || hop info < cached info) && packet is fresh enough && never received before {
              (3.1.1) cache the upstream node and the MRP-J info
              (3.1.2) IFQ-Size = IFQ-Size + N
              (3.1.3) IFQ-Size-Grp-Leader = IFQ-Size-Grp-Leader + N
              (3.1.4) if (F) ! = (S) forward MRP-J
              (3.1.5) end if
       (3.2) else
       (3.4)  ignore the MRP-J
       (3.5) end if
STEP4:
(4) Node (S) waits RREP_WAIT_TIME
       (4.1) if node (S) receives MRP-J within the time
       (4.2) Node (S) sends MACT message to activate the branch
       (4.2) else {
       (4.5) Node (S) becomes a GL after RREQ-RETRIES
       (4.6) Node (S) BROADCAST Group Hello Message}
       (4.7) end if
```

Figure 3.8 LB-MAODV algorithm

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3.4 Validation Test

This section represents a static scenario which has been tested by using the NS2.26 to validate the LB-MAODV protocol. Table (3.3) at the end of this chapter shows the simulation parameters that had been used in this static scenario. Figure (3.9) shows two multicast members, node (9) which represents the group leader in this multicast group and node (8) which represents the group member in the tree. Node (0) is a tree member since it is a router between the multicast group members. Node (7) decides to join the group thus it broadcast a join RREQ. In the Figure we can see that each node contains two numbers which show the node ID and the IFQ-Size respectively at that node.

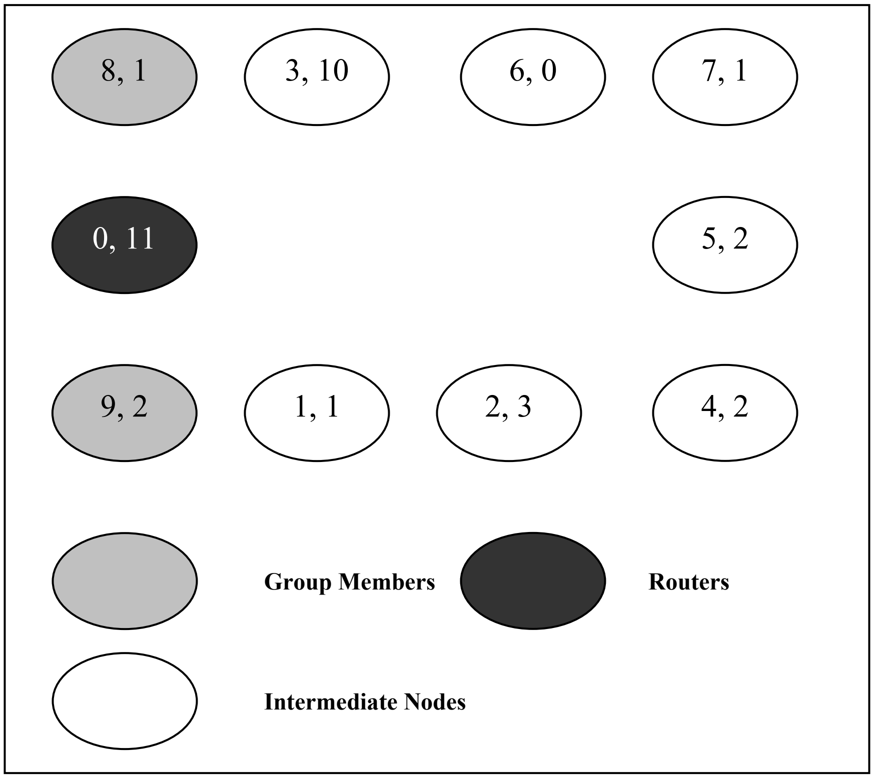

Figure 3.9 node 7 broadcast join RREQ

Nodes 6, 3,5,4,2 and 1, receive the join RREQ, update there unicast table, create the reverse route, add the node (7) information in the request table and then rebroadcast the request. Node (8) is a group member it receives the request from the node (3) then sends a

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join RREP packet and sets the IFQ-Size field to zero. Node (3) receives the RREP from the upstream node (8), adds its IFQ-Length to the total sum in the packet, creates the forward route in the unicast table, caches the upstream information in the multicast table without adding it since the path might latter becomes a branch in the tree and finally unicast it to the next node. The packet reaches to (6) the same procedure is performed too then it unicast the packet to node (7), node (7) caches the information of the upstream node (6) in the multicast table and caches the RREP packet information. Some of the RREP fields are shown in Table (3.1).

Table 3.1 RREP Packet from node (8)

RREP field	**Value**
IFQ-Size	10
IFQ-Size-Grp-Leader	22
Hop-Cnt	3
Hop-Cnt-Grp-Leader	5

Node (7) waits RREP_WAIT_TIME milliseconds because it might receive a better branch latter. The same process happens in the second path, the RREQ is broadcasted until it reaches to node (9) which represents the group leader in the tree. Node (9) sends join RREP with IFQ-size field initialized to zero. Each node receives the RREP adds its IFQ-Length to the total sum in the packet, caches the upstream node info and finally unicast it to the next hop. When node (7) receives the join RREP from the source node (9), it checks the load fields which contain the total sum of the IFQ-Length to each node in the path toward

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the tree and toward the group leader. Some of the received RREP fields are shown in Table (3.2).

Table 3.2 RREP Packet from node (9)

RREP field	Value
IFQ-Size	8
IFQ-Size-Grp-Leader	8
Hop-Cnt	5
Hop-Cnt-Grp-Leader	5

Node (7) compares those values with the cached value in the multicast table from the upstream node (6). Node (7) accepts the second reply which represents the maximum hop count toward the tree with the least load. The node (7) unicast a MACT message with (J-Flag) set to activate the branch to node (9) through the upstream node (5). Each node in the path receives the MACT message, stores the cached info in the multicast table, adds the upstream node from where it receives the RREP packet from, adds the downstream node from where it receives the MACT packet from and changes its identity to become router in the tree.

Figure (3.10) shows the selected route in the LB-MAODV protocol.

Figure (3.11) shows the selected route in the MAODV protocol.

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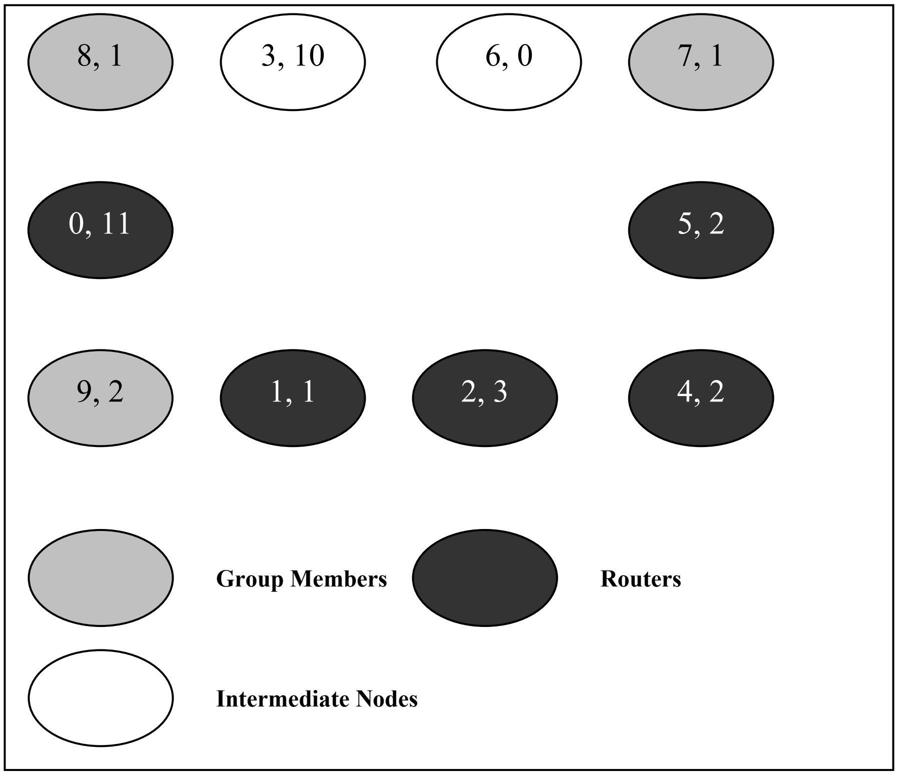

Figure 3.10 the least loaded route

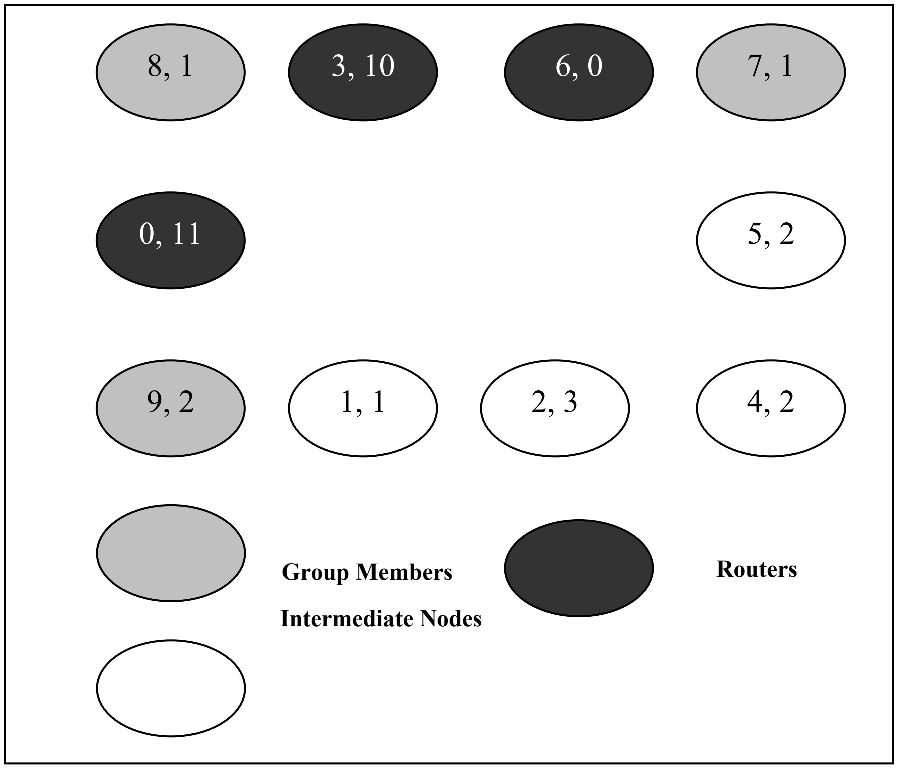

Figure 3.11 the minimum hop route

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Table (3.3) shows the simulation parameters used in the experiment.

Table 3.3 Simulation Parameters / static scenario

Parameter	Value
Data packet size	1024 bytes
MAC protocol	IEEE 802.11
Mobility model	Random waypoint
Mobility speed	0 m/s
Node placement	Customized Grid[1]
Number of nodes	10
Pause time	0 seconds
Propagation function	Two-Ray Ground
Radio range	250 meters
Simulation time	910 seconds
Simulator	NS-2.26
Terrain dimensions	1500*300 meters
Traffic type	CBR
Multicast groups	One
Multicast members	3
Multicast senders	1
Interface Queue Size	50 Packet

---

[1] The term Customized Grid used because non of the known Node Placement terms was applied in this scenario.

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4.1 Overview

In this chapter the characteristics of the PC that used in the experiments will be described. This chapter also describes the simulator which was used to simulate the different scenarios and obtain the results. The performance evaluation metrics which was used in this thesis also described.

4.2 System Specifications

A notebook PC was used to evaluate the experiments. Table (4.1) presents the system specifications.

Table 4.1 System Specifications

Item	Value
Processor	Intel CORE DUO CPU 667GHz
System Model	NBK SATELLITE A200 –1M5 TOSHIBA Notebook PC
Memory (RAM)	1024MB
OS Name	Linux Red Hat 9.0

4.3 The Simulator

NS-2 is a discrete event network simulator; many routing protocols in MANET are handy for NS-2, in addition to 802.11 MAC layer implementation. NS-2 combines two programming languages, the C++ and OTCL, which is an object oriented version of Tool Command Language (TCL) (Cavin, et al., 2002).

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This thesis uses NS version 2.26 (NS-2.26) to perform the required simulation. This version was specifically used because the last version of MAODV (Zhu and Kunz, 2004) code is consistent with NS-2.26. More information about NS2 is provided in the appendix.

4.4 Performance Evaluation Metrics

The sections below shows the performance metrics used in this thesis, with a little explanation for those metrics.

4.4.1 Packet Delivery Ratio

The packet delivery ratio (PDR) is the summation of all received data packets divided by summation of the sent data packets by all senders' times the number of receivers (Viswanath, et al., 2006). As shown in Equation (4.1).

$$\text{Packet Delivery Ratio} = \frac{\sum \text{Received Data Packets}}{\sum \text{Sent Data Packets} * \text{receivers number}} \quad \text{.... ... (4.1)}$$

This metric used to show fitness of the protocol in transmitting data packets to the required receivers.

4.4.2 Latency

The latency measure the end-to-end delay. This represents the time since the data packets have been sent from the senders till they reach the receivers. The number of senders and receivers affect the delay in multicast routing protocols. The delay encloses the send buffer delay, the interface queue (IFQ) delay, the delay caused by bandwidth contention at the Medium Access Control (MAC) and finally, the propagation delay (AL Mobaideen, et al., 2007) (Zhu and Kunz, 2004). In this thesis the latency measured by seconds.

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4.5 Improvement Ratio

To compare between the LB-MAODV and the MAODV protocols and confirm the enhancement obtained by LB-MAODV about the chosen performance metrics and parameters the improvement ratio is provided. The improvement Ratio (IR) of both protocols can be obtained according to Equation 4.2.

IR= (L- M) / L …………………………………………………………………………… (4.2)

Where L: value of LB-MAODV.

M: value of MAODV.

4.6 Preparations of the system environment

The following steps were followed in this work:

1. Linux Red Hat 9.0 was installed as mentioned in section 4.2.
2. The NS2.26 version was installed as mentioned in section 4.3.
3. The NS2.26 version was validated by test the included examples in the version.
4. The MAODV code was installed by following the same steps as mentioned in (Zhu and Kunz, 2004) report.
5. The obtained results were compared with the results in (Zhu and Kunz, 2004) report to validate the code and to create the new code.
6. The new protocol was tested with mobility model.
7. The experiments were done to compare both protocols behaviors in high traffic network; this will be explained in chapter (5).
8. The results were analyzed and compared as it will be shown in chapter (5).

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4.7 MAODV Specifications

The standard implementation of AODV, is included in NS2. The multicast extension of the AODV is the MAODV it has two implementation versions. The first one developed by (Cheng, 2001), it was limited by two restrictions. Firstly, the multicast traffic can be initialized only by group members. Secondly, unicast communication is used to transmit the multicast data packets to group members which wastes the bandwidth.

The second version of MAODV developed by (Zhu and Kunz, 2004) overcomes those restrictions, by allowing each member in the network to send multicast data packets. The protocol also broadcast the multicast data packets between group members in the tree instead of unicast them to save the bandwidth. This thesis uses (Zhu and Kunz, 2004) version.

Nodes in the network send the data packets to the multicast tree in two steps according to (Zhu and Kunz, 2004) version. First, the node finds a route to the tree using the same RREQ and RREP cycles that used in AODV protocol. The node can either broadcast or unicast the request according to the available information in the Group Leader Table. The version uses the Group Leader Table; it contains the functions of the Request Table that used in the AODV protocol. The second step is done by the group member that receives the data packets it broadcast them to the other group members in the tree.

The protocol uses the MAC layer detection to detect the link breakage in the route to the tree. In the tree the protocol couldn’t use the MAC layer detection for link breakage because the protocol uses the broadcast mechanism to forward data packets within the tree. Instead the protocol uses one hop neighbor hello messages to find the link breakage, if the node detects a link breakage it creates a RREQ to find a new route. The neighbor hello overhead can be reduced by delaying the message when the node sends packets.

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5. Simulation Results and Analysis

5.1 Overview

In this chapter, the simulation experiments that were used in this study will be described in details. The simulation parameters also will be highlighted. Their effect on the behavior of both protocols; LB-MAODV and MAODV will be explained. All of the results of the simulation experiments and their parameters will be presented using tables and figures.

5.2 Performance Evaluation When Varying Group Size

The following two experiments were done to show the effect of varying group size on the behavior of both protocols; MAODV and LB-MAODV protocols. In each experiment different number of senders has been used. In the first experiment the number of senders was (2) and in the second experiment the number of senders was (5). The number of receivers was (10, 20, 30, and 40) for each experiment. The mobility speed was (1) m/s. The inter packet gap interval of the CBR traffic source was (0.05) which means 20 packets/seconds. The simulation time was (910) seconds. The terrain dimensions values were chosen based on (Kunz, 2003) and (Zhu and Kunz, 2004) studies.

The parameters of simulation environment that used in the following set of experiments are summarized in Table (5.1).

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Table 5.1 Simulation Parameters / Varying Group Size

Parameter	Value
Data packet size	1024 bytes
MAC protocol	IEEE 802.11
Mobility model	Random waypoint
Max mobility speed	1m/s
Multicast groups	One
Multicast members	Variable
Multicast senders	Variable
Node placement	Random
Number of nodes	50
Average pause time	0 s
Propagation function	Two-Ray Ground
Radio range	250 meters
Simulation time	910 seconds
Simulator	NS-2.26
Terrain dimensions	(1500 * 300) meters
Traffic type	CBR
Packets per second	20
Interface Queue Size	50 Packet

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5.2.1 Experiment (1)

Packet Delivery Ratio Regarding Group Size

In the following experiment, there were two senders and variable receivers. The values of receivers were (10, 20, 30, and 40). The PDR was measured while varying the value of receivers. The two protocols were examined and the results were shown in Figure (5.1). The PDR for the LB-MAODV protocol is higher than the PDR of the MAODV protocol. This is due to the increment in the traffic load which makes the LB-MAODV depends on the amount of lined up packets in the interface queue along the path to select the route. The LB-MAODV protocol also can select the path with the least hop count and the least load. Whereas, MAODV doesn't consider congestion problems since it depends on minimum hop count only when building the tree.

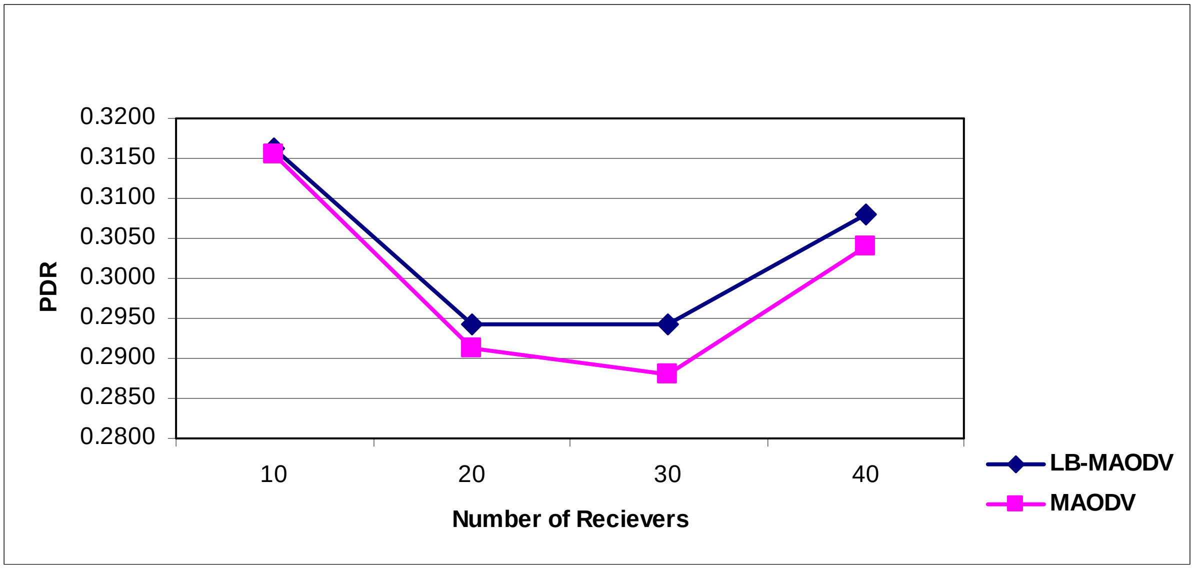

Figure 5.1 Packet Delivery Ratio as a Function of Group Size / 2 Senders

In addition to congestion, the PDR and Latency metrics in this experiment were affected by two elements; the probability of collisions and the connectivity of the tree. Both factors affect each other. Three cases can be noticed in Figure (5.1). The PDR for both

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protocols decreases when the number of receivers increased from (10) to (20). This might be due to collisions. The PDR is almost steady when number of receivers within the interval [20-30]. This is because both elements, the connectivity and collisions, balanced each other. However, when the number of receivers is larger than (30) the effect of connectivity becomes higher than the effect of collisions on the PDR since the PDR is increased.

Latency Regarding Group Size

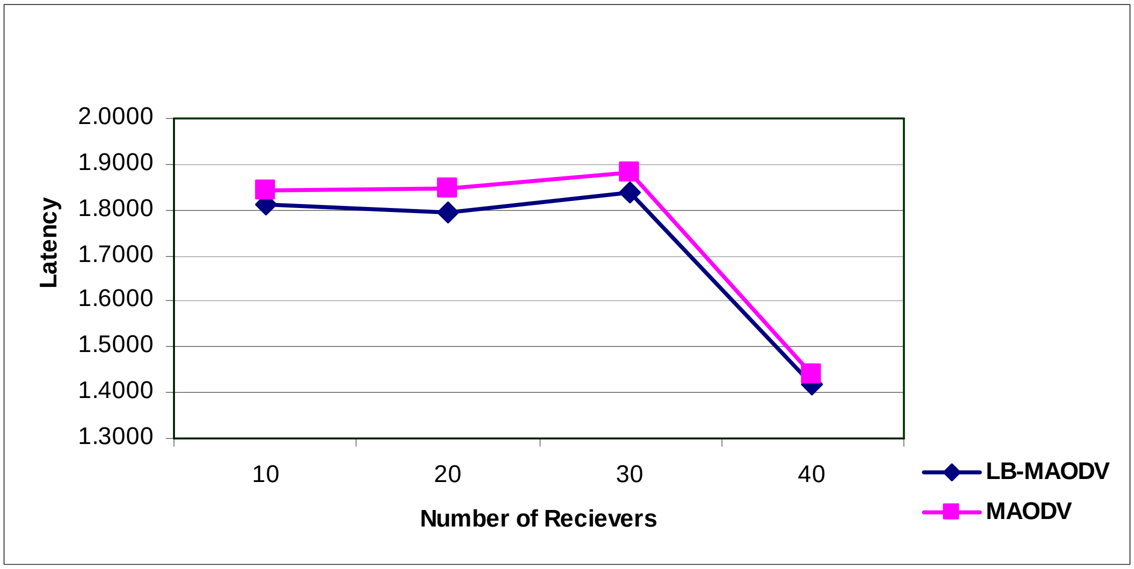

Figure 5.2 Latency as a Function of Group Size / 2 Senders

Figure (5.2) displays the latency of both protocols MAODV and LB-MAODV with a network consisting of 50 nodes. Two of them were senders while the number of multicast members which represents the number of receivers in the tree was varied. One can see that the latency of LB-MAODV is always lower than the latency of MAODV regardless the number of receivers. This is because the LB-MAODV protocol selects the route that avoids

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congestion in high traffic network which reduces the packets waiting time inside the nodes queue.

It can be noticed that both protocols are generally unaffected very much by the traffic rate in the interval [10-30]. The latency in both protocols decreases when the number of receivers is larger than (30), this is due to the increment in the number of receivers. Because the received data packets are broadcasted within the tree, this is the MAODV strategy to distribute the multicast traffic on the multicast members (Royer and Perkins, 1999). The increment in the number of receivers increases the number of interested nodes in the multicast traffic. Hence, more data packets can be received in each broadcast within the tree which reduces the latency (Kunz, 2003) (AL-Mimi, 2005) (AL Mobaideen, et al., 2007).

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5.2.2 Experiment (2)

Packet Delivery Ratio Regarding Group Size

In the second experiment, there were five senders and the number of receivers was variable. The values of receivers which represent the group members in the tree were (10, 20, 30, and 40). Figure (5.3) represents the PDR for both protocols the LB-MAODV and the MAODV protocol in terms of the number of receivers. It can be noticed that the PDR for the LB-MAODV is higher than the MAODV protocol this due to the fact that the LB-MAODV selects the least loaded route while the MAODV selects the shortest route.

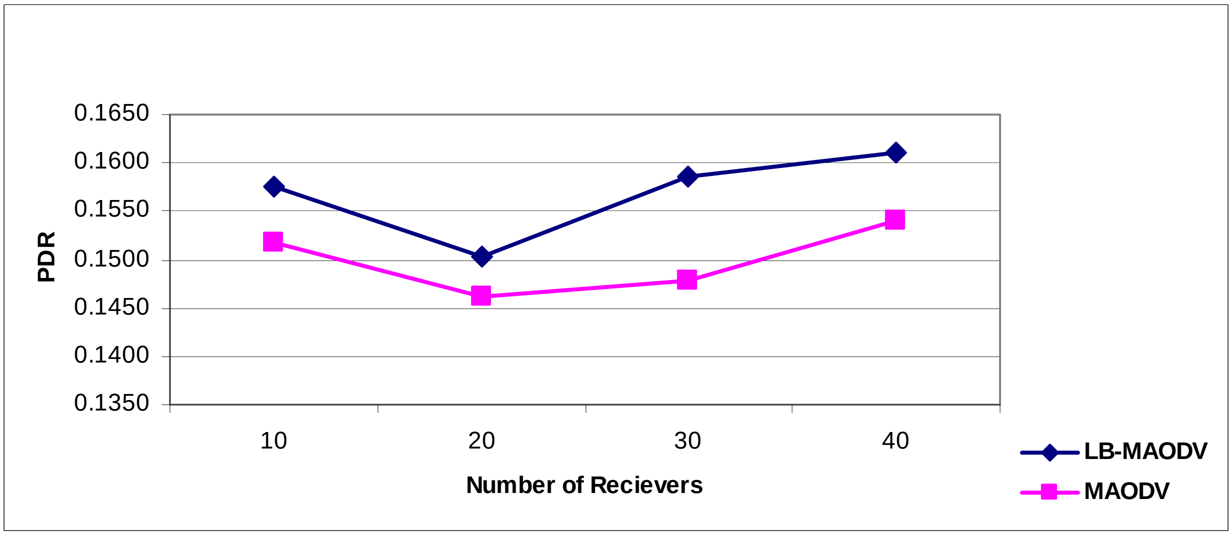

Figure 5.3 Packet Delivery Ratio as a Function of Group Size / 5 Senders

Moreover, LB-MAODV works well as group size increase, which means that the protocol provides group communication which confirms the scalability of the protocol. The PDR decreases when the number of senders is (20) this due to collisions then the PDR increases within the interval [30-40] this is due the connectivity of the tree.

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Latency Regarding Group Size

Figure (5.4) illustrates the latency in both protocols MAODV and LB-MAODV in terms of number of receivers. The number of senders in this experiment is higher than the number of senders in experiment one which increases the traffic load in the network. One can see that the latency in the LB-MAODV protocol is lower than the latency of MAODV protocol regardless the number of receivers in the network. This is because the LB-MAODV selects the route with the idlest nodes in the network while the MAODV selects the shortest route which might contain congested nodes. Hence, data packets enforced to stay longer in the nodes queue which will increase the latency in the MAODV protocol.

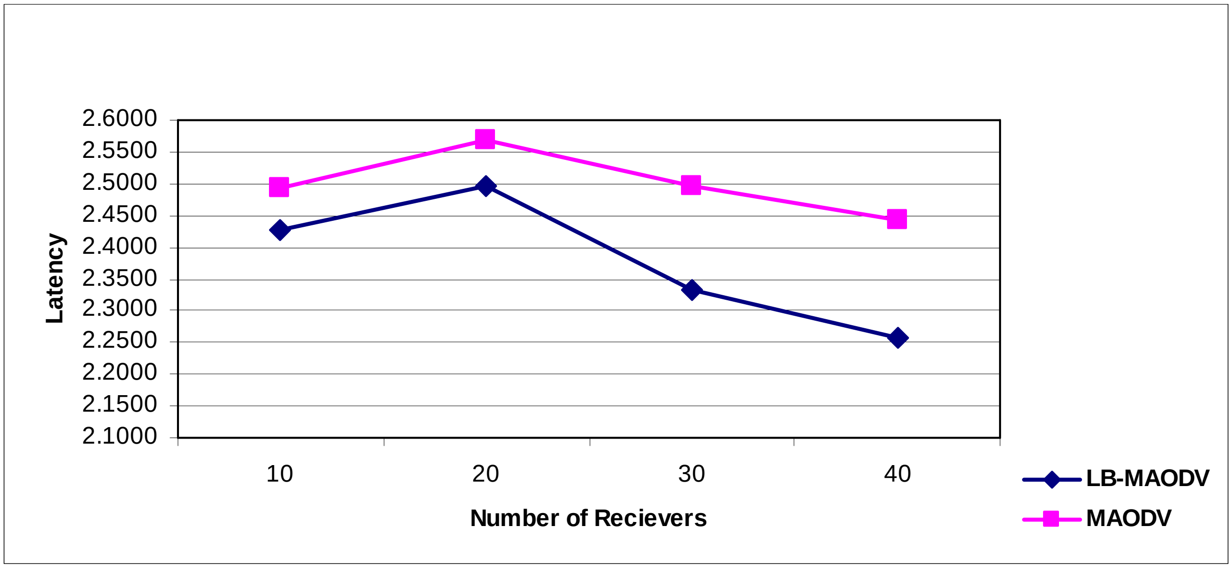

Figure 5.4 Latency as a Function of Group Size / 5 Senders

Moreover, as the number of receivers increases the difference between the performances of the two protocols becomes higher. This is because the network traffic is high in this experiment which increments the congestion possibility. Hence, LB-MAODV protocol provides lower latency since it avoids congestion.

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In the Figure the latency increases when the number of receivers is (20) this is because of contention which enforces packets to stay longer in queues. The latency decreases in the interval [20-40] because the increments in the number of receivers increase the amount of data that can be received in each broadcast which decreases the latency.

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5.3 Performance Evaluation when varying Terrain Dimensions

The following two experiments were done to show the effect of Terrain size on the behavior of both protocols the MAODV and the LB-MAODV while varying the size of multicast group members in the multicast tree.

Table 5.2 Simulation Parameters / Varying Terrain Dimensions

Parameter	Value
Data packet size	1024 bytes
MAC protocol	IEEE 802.11
Mobility model	Random waypoint
Max mobility speed	1m/s
Multicast groups	One
Multicast members	Variable
Multicast senders	2
Node placement	Random
Number of nodes	50
Average pause time	0 s
Propagation function	Two-Ray Ground
Radio range	250 meters
Simulation time	910 seconds
Simulator	NS-2.26
Terrain dimensions	Variable
Traffic type	CBR
Packets per second	20
Interface Queue Size	50 Packet

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5.3.1 Experiment (1)

Packet Delivery Ratio Regarding Terrain Dimensions

In a network of 50 nodes, we examined both protocols LB-MAODV and MAODV, having 10, 20, 30 and 40 receivers and terrain size (100 * 100) meter. The other parameters were summarized in Table (5.2). The results are illustrated in Figure (5.5). It can be noticed that the PDR of the LB-MAODV is always higher than MAODV despite the number of receivers. This is due to the fact that LB-MAODV uses the IFQ-Length as primary route metric selection which helps avoiding congestion in high traffic network. Whereas MAODV uses the minimum hop count metric to select the route.

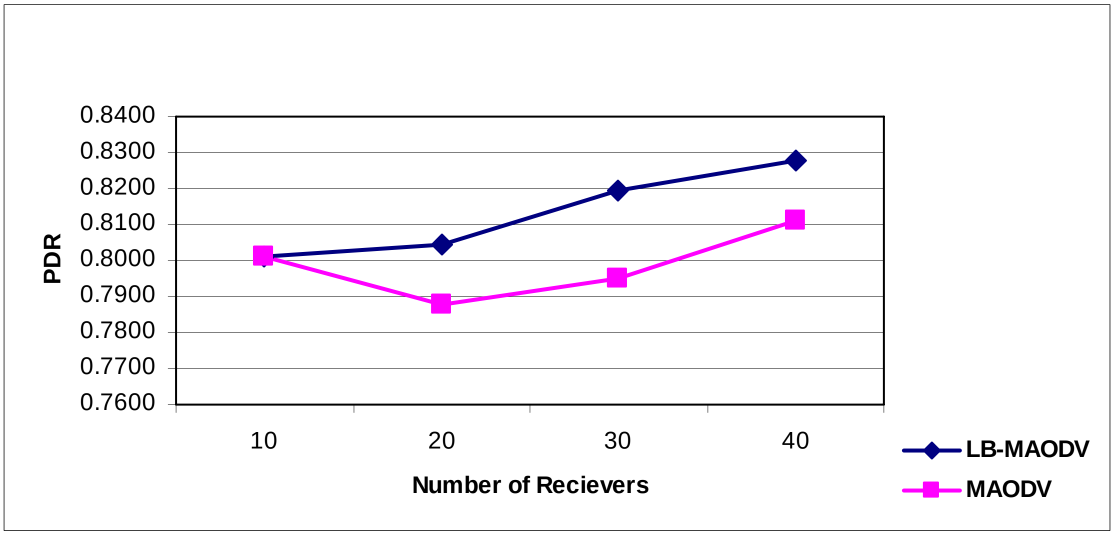

Figure 5.5 Packet Delivery Ratio for 100m x 100m Multicast simulations

Also, as the number of receivers increase the difference between the performances of the two protocols becomes higher. This is due to the fact that smaller network size becomes denser which increases the possibility of congestion. The LB-MAODV selects the route with the underloaded nodes, whereas MAODV might select the route that contains the overloaded nodes.

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Furthermore, tree maintenance is easier in small terrain than large terrain size because reconnecting the multicast tree and the maintenance of link breakage takes less time than larger dimensions (Royer and Perkins, 1999). Thus the PDR always increases in both protocols.

Latency Regarding Terrain Dimensions

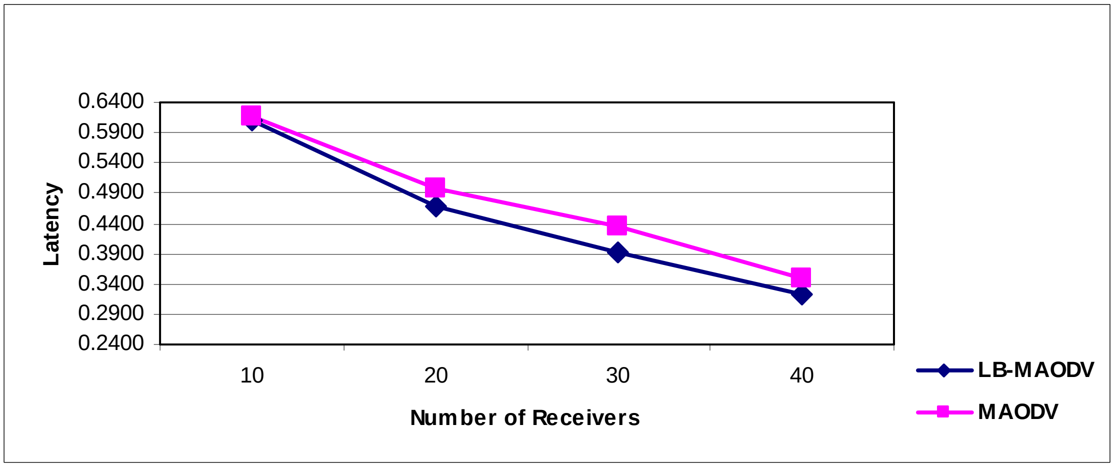

Figure 5.6 Latency for 100m x 100m Multicast simulations

Figure (5.6) displays the latency of both protocols while varying the number of receivers in small terrain size. One can see that the latency in LB-MAODV is always lower than latency in MAODV. This is due to the fact that both of them select different route in a high traffic network and the LB-MAODV selects the least loaded one. Hence, packets arrive faster.

Furthermore, the latency in both protocols decreases while number of receiver's increases. This is because the network is more connected since the terrain size is small thus more data packets can be received in each broadcast which will reduce the latency (Royer and Perkins, 1999).

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5.3.2 Experiment (2)

Packet Delivery Ratio Regarding Terrain Dimensions

In this experiment the same simulation parameters in Table (5.2) were used. Figure (5.7) depicts the PDR for both protocols with variable number of receivers within 1000 * 1000 terrain size. We can see that the PDR to the LB-MAODV protocol is always higher than the MAODV protocol since it avoids congestion in the network. Besides, the difference between the performances of the two protocols becomes higher since the LB-MAODV selects the route that avoids congested nodes. As a result, the amount of delivered data packets in the LB-MAODV protocol is higher than the MAODV protocol.

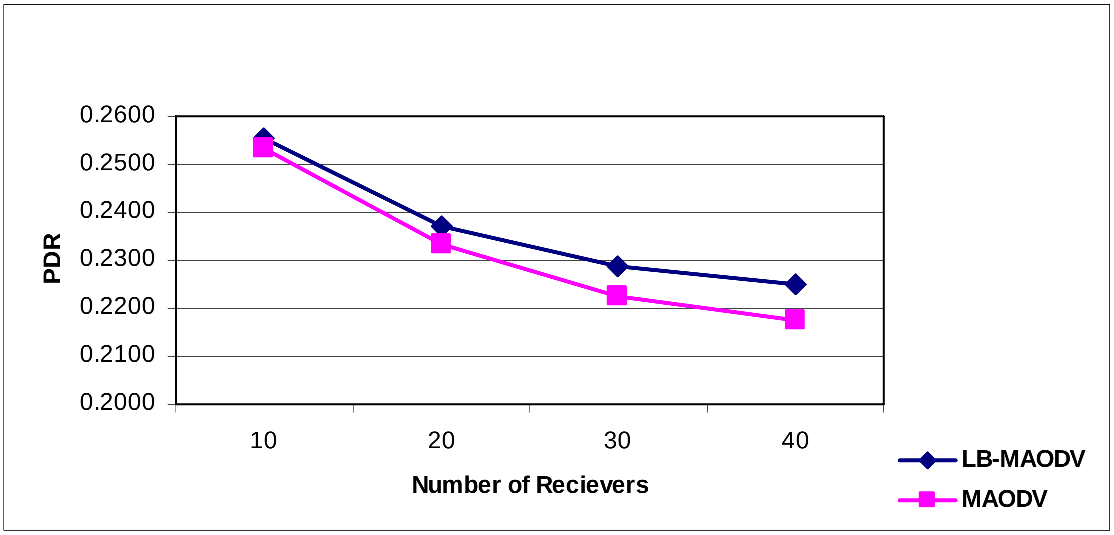

Figure 5.7 Packet Delivery Ratio for 1000m x 1000m Multicast simulations

Moreover, as the number of receivers increases the PDR curve decreases. Because the large terrain dimensions creates many clusters of nodes that contains multicast groups members. Each of them has its own group leader with the same multicast address (Royer and Perkins, 1999). Hence, route maintenance is needed which increases the congestion and decreases the PDR since the tree is partitioned.

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Latency Regarding Terrain Dimensions

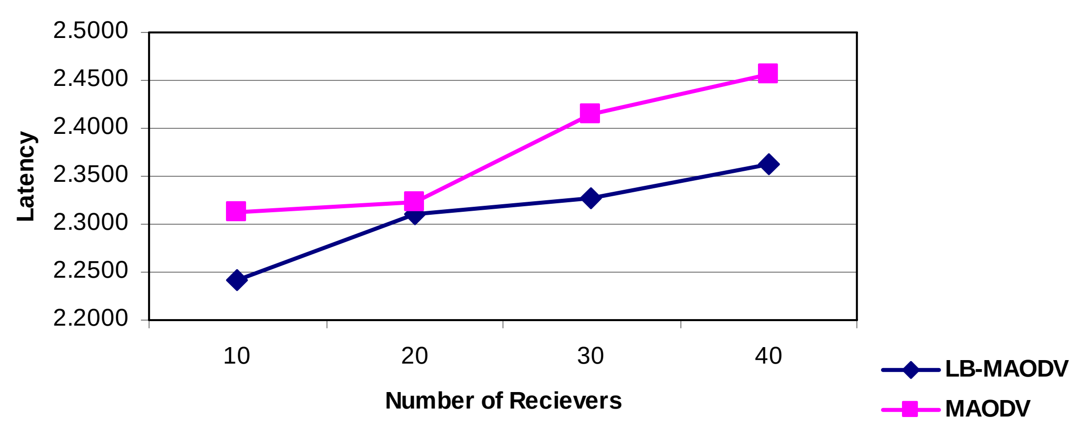

Figure 5.8 Latency Ratio for 1000m x1 000m Multicast simulations

Figure (5.8) demonstrates how latency varies with the number of receivers within terrain size 1000 * 1000 meter. One can see that the latency of the LB-MAODV protocol is lower than the MAODV protocol regardless the number of receivers in the network. This is due to the fact that LB-MAODV protocol looking for the route with the minimum congested nodes. While MAODV protocol takes the route with the minimum hops which can not guarantee delivering packets since the selected route might be congested.

Moreover, LB-MAODV protocol provides better performance in terms of latency, because the tree was split into many multicast tree partitions which enforce some packets to stay longer in the nodes queue. The previous situation leads to congestion and longer delay. The MAODV protocol might select this path while LB-MAODV protocol will avoid this congested path. The latency increases in the interval [10-40]. This is due to the disconnection in the tree since the network size is large.

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5.4 Performance Evaluation When Varying Number of Senders

The following experiment was done to show the effect of varying number of senders, on the behavior of both the MAODV protocol and the LB-MAODV protocol. The parameters of simulation environment that used in the following set of experiments are summarized in Table (5.3).

Table 5.3 Simulation Parameters / Varying Number of Senders

Parameter	Value
Data packet size	1024 bytes
MAC protocol	IEEE 802.11
Mobility model	Random waypoint
Max mobility speed	1m/s
Multicast groups	One
Multicast members	30
Multicast senders	Variable
Node placement	Random
Number of nodes	50
Average pause time	0 s
Propagation function	Two-Ray Ground
Radio range	250 meters
Simulation time	910 seconds
Simulator	NS-2.26
Terrain dimensions	(1500 * 300) meters
Traffic type	CBR
Packets per second	20
Interface Queue Size	50 Packet

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5.4.1 Experiment (1)

Packet Delivery Ratio Regarding Number of Senders

In this experiment, there were (30) receivers and the number of senders was varied. The values of senders were (2, 5, 10, and 15). Figure (5.9) demonstrates the PDR of the two protocols while the number of senders is increasing. It is clear that the LB-MAODV has higher PDR than the MAODV and this is because of LB-MAODV ability to select the path with the lightly loaded nodes in a high traffic network whereas MAODV selects the shortest path which can not avoid the congestion.

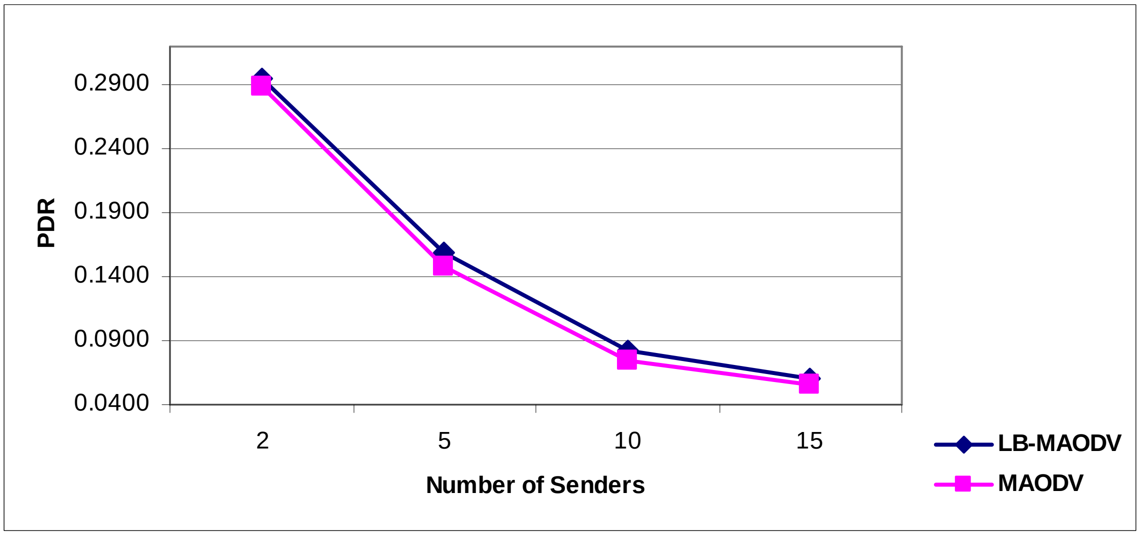

Figure 5.9 Packet Delivery Ratio as a Function of number of senders

Moreover, as the number of senders increases the PDR decreases. This is due to the fact that the traffic load in the network gets larger when the number of senders increases. The increment in the network load leads to congestion at some nodes and more contention between nodes to enter the wireless channel. However, the PDR of the LB-MAODV protocol is higher than that for MAODV protocol since it avoids congestion.

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Latency Regarding Number of Senders

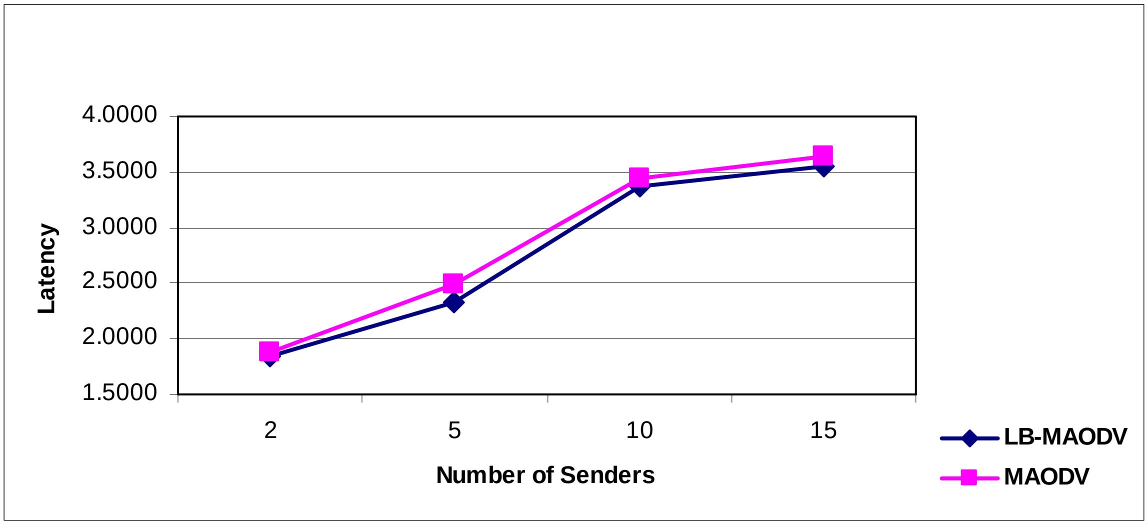

Figure 5.10 Latency as a Function of Number of Senders

Figure (5.10) illustrates a comparison between LB-MAODV and MAODV protocols in terms of number of senders. It can be noticed that the Latency of LB-MAODV is always lower than MAODV while changing the number of senders. This is because LB-MAODV protocol ability to avoid the heavily loaded nodes in a high traffic network which reduces the packets waiting time inside the nodes queue.

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6. Conclusions and Future Work

6.1 Conclusions

This thesis presents the Load Balancing Multicast Ad-Hoc On Demand Distance Vector (LB-MAODV) protocol. The protocol reduces the packet drop rate and the average end-to-end delay by selects the least loaded route in highly loaded network. The protocol depends on the IFQ length metric selection to build the minimum congested tree instead of minimum hop tree. Different scenarios were created and implemented using NS2 simulator.

Different performance metrics were used to compare between MAODV and LB-MAODV includes the Packet Delivery Ratio (PDR) and the average end-to-end delay. Number of senders, number of receivers and terrain dimensions were chosen as performance parameters to MAODV and LB-MAODV to the pervious performance metrics.

The first set of experiments compare between the LB-MAODV protocol and MAODV protocol in term of different number of senders and different number of receivers. The results show that the LB-MAODV provides higher Packet Delivery Ratio (PDR) and lower Latency. The second set of experiments compare between both protocols in two different Terrain dimensions. Different numbers of receivers have been used in many scenarios. The LB-MAODV protocol gives better results in the selected dimensions. The last experiment shows the effect of varying number of senders on both protocols, the results show that the LB-MAODV performs better in high traffic network.

To compare between MAODV and LB-MAODV protocols we show the Improvement Ratio to the LB-MAODV regarding to the selected performance metrics and

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parameters. Tables (6.1) (6.2) show the PDR and Latency improvement ratio obtained by LB-MAODV respectively.

Table 6.1 PDR improvement ratio

Performance Parameter	IR
Variable Number of Receivers / 2 Senders	1.16%
Variable Number of Receivers / 5 Senders	4.37%
Variable Terrain Dimensions / 100x100 meter	1.77%
Variable Terrain Dimensions / 1000x1000 meter	2.09%
Variable Number of Senders / 30 Receivers	6.10%

Table 6.2 Latency improvement ratio

Performance Parameter	IR
Variable Number of Receivers / 2 Senders	2.15%
Variable Number of Receivers / 5 Senders	4.88%
Variable Terrain Dimensions / 100x100 meter	6.08%
Variable Terrain Dimensions / 1000x1000 meter	2.78%
Variable Number of Senders / 30 Receivers	3.46%

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6.2 Future Work

Our case study on this thesis was MAODV routing protocol. The thesis gives us a clue that more investigation on the concept of Load-Balancing for ad hoc multicast routing protocols may enhance their state. Better results may be achieved by modifying the current protocols or even by creating new protocols that address a lot of issues related to ad hoc networks in addition to Load-Balancing concept such as energy and bandwidth constraints. Moreover, the thesis was performed by the existence of multicast traffic only. Depending on the results it is recommended to apply the study using both unicast and multicast traffic. Also, there was only one multicast group in this thesis, it is recommended to apply the study with multiple multicast groups in order to study the effect of that on the LB-MAODV protocol.

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APPENDIX

1. NS-2 Simulator

The network simulators should be able to perform two things. First of them is the protocol details which need a programming language that strongly handling bytes, packet headers and running algorithms that require huge set of data. Secondly, the large network requires different parameters and quick scenarios for verification. So the need for fast strategy to make changes and re-run is very important. NS-2 simulator satisfy those requirements, by using C++ language for implementing protocols because it is fast to run but slower to change, and OTcl for simulation configurations because it is fast to change but slower to run (The VINT Project, 2008).

2. NS-2 Class Hierarchy

Figure (1)[1] shows a partial NS2 class hierarchy, in order to understand the characteristic of the network.

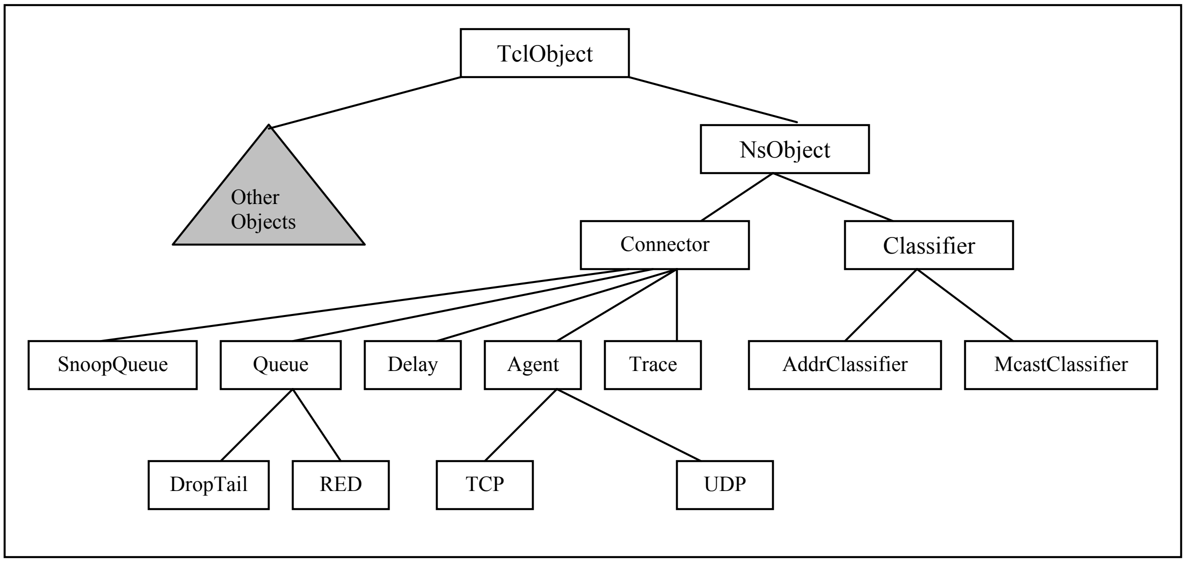

Figure 1 partial ns-2 class hierarchy

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3. Mobile Nodes

Figure (2)[2] represents the mobile nodes schematics.

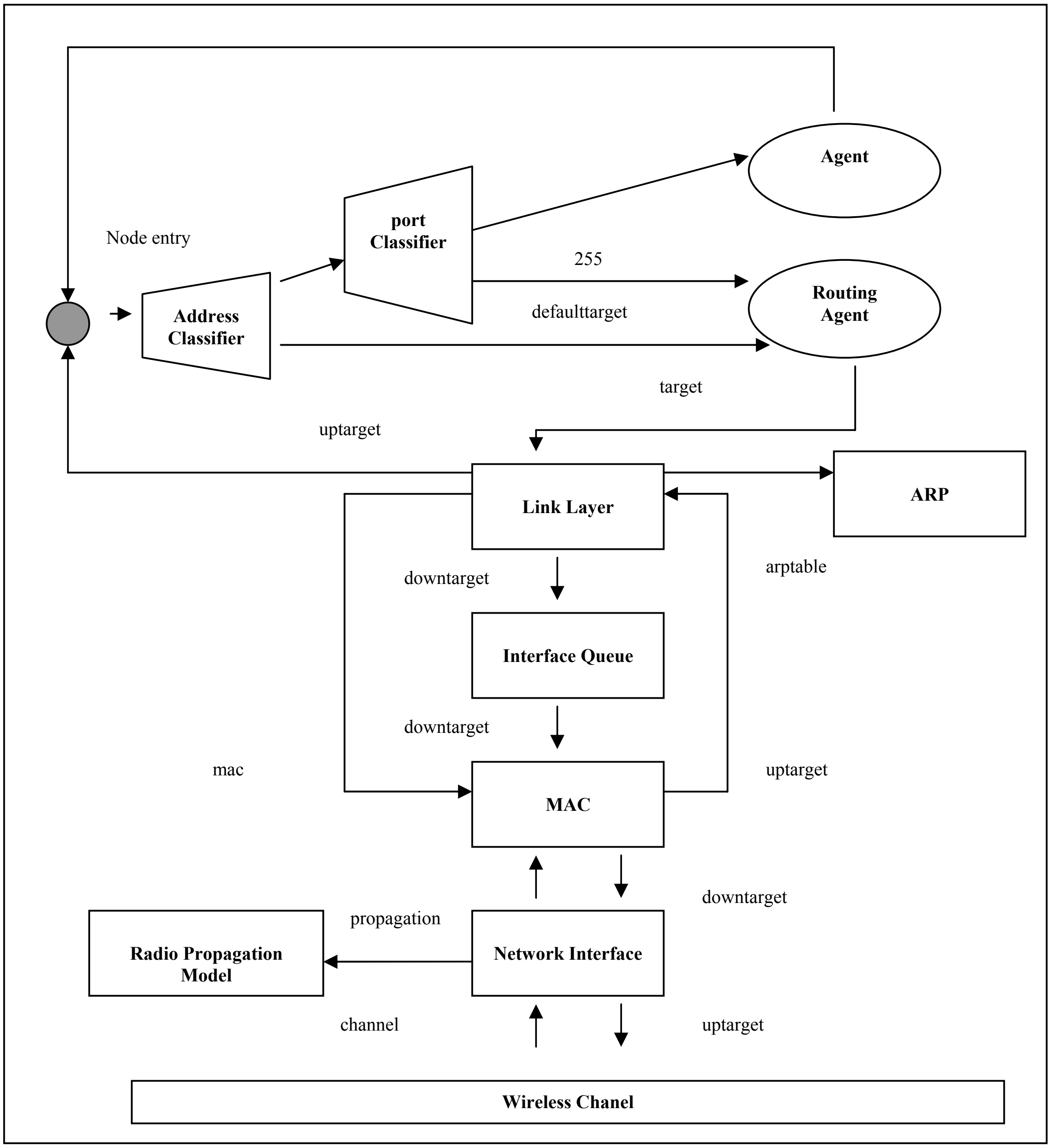

Figure 2 Schematics of mobile node in ns-2

1, 2 those figures were taken from (Wiberg, 2002)

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تجنب الازدحام في بروتوكولات النقل المتعدد

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ملخص

الشبكات المتنقلة العشوائية (MANET) تجتذب العديد من الباحثين لأنها تستخدم في المناطق التي لا تتواجد فيها الشبكات السلكية . المحددات الموجودة في الشبكات اللاسلكية (MANET) تجعل تطوير بروتوكولات النقل المتعدد أصعب من تطويره في الشبكات السلكية. بروتوكولات النقل المتعدد تصنف إلى بروتوكولات الجداول المشتقة وبروتوكولات حسب الطلب وذلك حسب المعلومات المتوافرة عن الشبكة. كما تصنف إلى البروتوكولات الشجرية والبروتوكولات الشبكية حسب تراكيب البيانات المستخدمة لنقل حزم البيانات.

يعد بروتوكول (MAODV) من أشهر البرتوكولات الشجرية. بروتوكول (MAODV) هو بروتوكول شجري ويطلب الطريق (Route) فقط عند الحاجة. بروتوكول (MAODV) يستخدم أسلوب الطريق الأقصر لاختيار الطريق بين المرسل و المستقبل. على كل حال، الطريق الأقصر لا تعتبر الحل الأمثل في الشبكات المزدحمة. وذلك لأن هذه الطرق لا تضمن توصيل حزم البيانات بالإضافة إلى الإمكانية العالية لحدوث الازدحام و التأخير. هذه الدراسة تقدم بروتوكولا جديدا والذي يستخدم (Interface Queue Length) كطريقة رئيسية لاختيار الطريق الأقل ضغطا في الشبكات الكثيرة الازدحام بدلا من اختيار الطرق القصيرة. البروتوكول الجديد يسمى بروتوكول (LB-MAODV) وبالتالي سيتم إنشاء الشجرة ذات الطرق الأقل ازدحاما بدلا من الشجرة ذات الطرق الأقصر.

كفاءة وفعالية البروتوكول تم فحصها باستخدام برنامج محاكاة الشبكات (NS2) وتمت مقارنته مع بروتوكول (MAODV) . وقد أظهرت النتائج أن بروتوكول (LB-MAODV) عمل على تحسين الاتصالات في الشبكات العالية الازدحام. حيث كان معدل نسبة التحسين في توصيل حزم البيانات 3 % ومعدل التحسين في تقليل التأخير ٤%. وكان معدل التحسين الكلي هو ٣,٥%.

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