Multicast Communication in Cartesian Networks

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ABSTRACT

A Cartesian network is a modified two-dimensional mesh network consisting of horizontal and vertical networks. At present, two 'traditional' protocols exist for the network: a unicast protocol, and a loop-free broadcast protocol. With the increasing number of multicast applications, there is a clear need for Cartesian Networks to support multicast communications. This paper presents three Cartesian multicast protocols and their simulation results

Categories and Subject Descriptors

C.2.2 [Computer – Communication Networks]: Network Protocols --- Routing Protocols.

General Terms

Algorithms, Performance, Design.

Keywords

Multicast routing, Cartesian Network, Broadcast.

1. INTRODUCTION

A Cartesian network consists of a set of collectors and one or more arterials, as shown in Figure 1. Each collector is a chain of collector routers running east west sharing a common latitude. Collector routers have two ports (east and west) to exchange packets “horizontally”. Each collector router also has a local port, which allows it to connect to a set of local hosts.

Arterials exchange packets between collectors. Each arterial router, except the most northerly and the most southerly, has, at least, four ports (north, south, east and west). Arterials need not share a common longitude.

In a Cartesian network, the imposed topological structure relieves each router of maintaining routing tables. Each router is bound to a unique address (for example, a latitude and longitude). Both collector and arterial routers implement the linear routing algorithm: collector routers examine latitudes while arterial routers examine both latitudes and longitudes.

On a multicast network, a single packet of information from one node can be sent to several other nodes at the same time, rather than having to be sent once for each destination. Deploying multicast routing technology means that bandwidth is conserved. Nowadays, with the increasing demand for multicast transmission, there is a clear need for the Cartesian Networks to support multicast communication.

2. BACKGROUND

In traditional networks, communications are divided into two types: unicast which is between two nodes and broadcast which is between one node and all the other nodes. Both computer and telecommunication industries have been developing very rapidly. Many new applications have emerged and have given new requirements to computer networks. LAN TV, desktop conferencing, corporate broadcasts and collaborative computing require simultaneous communications among a group of computers. A computer will send data or a multimedia stream to the other computers in this group [1][2].

Currently, the Cartesian Networks support the two traditional communication methods: unicast communications and broadcast communications.

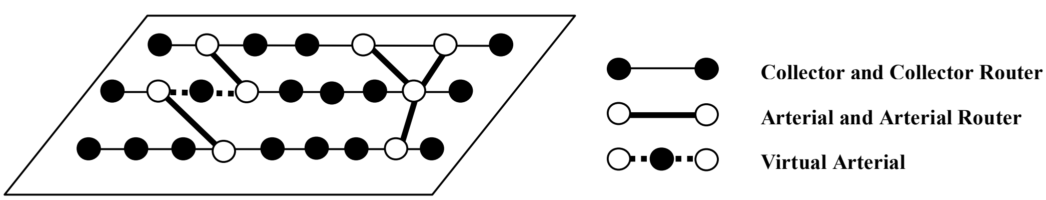


Figure 1. A Cartesian Network

With today's technology, it is possible in a Cartesian Network to afford the "cost" of a unicast connection for such applications as file transfer. However, for multimedia traffic such as audio and video, which requires a large amount of bandwidth compared with file applications, there are two available options: establish a separate unicast connection with each of the recipients, or use broadcast. Since a single connection sending audio and video consumes a large bandwidth, hundreds or even thousands of connections could cause both the sender and network to collapse [3][4].

In Cartesian Networks, broadcast may be the best solution for new applications. If all the hosts in a Cartesian Network need the packets, broadcast is available. Packets will be sent only once and every host will receive them as they are sent to the broadcast address. However, if only some of the hosts are interested in these packets, then hosts who do not need these packets have to waste resources processing them.

This research considers alternatives to using Cartesian Unicast and Broadcast to support multicast communication.

3. DESIGN AND IMPLEMENTATION

3.1 Introduction

A total of six Cartesian multicast routing protocols have been designed and three of them have been simulated in the OPNET Modeler [8]. In this section, the three Cartesian multicast protocols that have been simulated will be discussed. The three protocols are: Multicast Extensions to Unicast Cartesian Routing Protocol (MEUCR), Multicast Extensions to Broadcast Cartesian Routing Protocol (MEBCR), Cartesian Geographical Multicast Routing Protocol (CGM).

3.2 Multicast Extensions to Unicast Cartesian Routing Protocol (MEUCR)

In this approach, as shown in Figure 2 below, each multicast source router sends its packet to the Active Multicast Router (AMR). The destination address of the packet is the group sequence number. The Multicast Router maintains a table of the membership information for all groups. When a multicast packet arrives at the AMR, it looks up its multicast routing table to find the unicast Cartesian address of all members of the destined group. It sends a copy of that packet to the unicast Cartesian address of each group member individually. In this way, all destination multicast group members will receive a copy of the multicast packet.

3.2.1 Topology

In this approach, as shown in Figure 2 below, two collector routers are designed to serve as Active Multicast Router (AMR) and Backup Multicast Router (BMR) for the entire Cartesian Network. Both of the two Multicast Routers maintain the multicast routing table of the whole Cartesian Network. The multicast routing table includes multicast group sequence number, destination latitude and destination longitude. One bit is designed to be the status flag in both AMR and BMR. When the flag is set to "1", the multicast router is considered to be the AMR. When the flag is set to "0", the multicast router is considered to be the BMR.

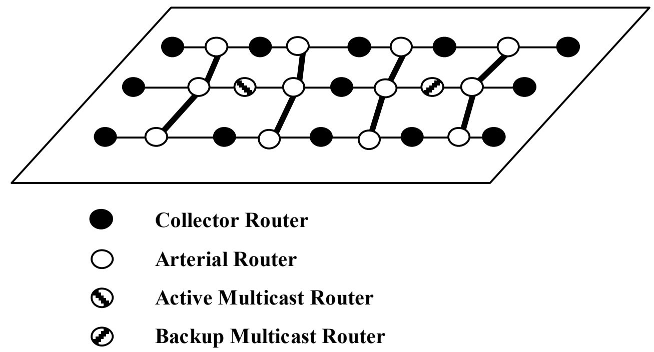


Figure 2. MEUCR Network

3.2.2 Packet Structure

Since this protocol is based on the Unicast Cartesian Routing algorithm [6], the multicast packet is also derived from a unicast packet and is shown in Figure 3 below. The "M" and "MID" are extended to the unicast packet. The "M" field indicates whether the packet is a unicast packet (0000), a broadcast packet (0001) or a multicast packet (0010).

M	MID	DLA	DLO	SLA	SLO	Payload

MEUCR Packet

Figure 3. Structure of the MEUCR Packet

The "DLA","DLO","SLA","SLO" indicate the destination and source latitude and longitude, which all have 24 bits. "MID" field has 16 bits and is the multicast group sequence number.

3.2.3 Routing Mechanism

At the initialization stage of the Cartesian Network, the Active Multicast Router (AMR) broadcasts its unicast Cartesian address to all the routers within the network. The broadcast packet is routed following the Cartesian Broadcast Routing algorithm [5]. Each router maintains the unicast Cartesian address of the AMR of the entire Cartesian Network.

In the Broadcast Cartesian Routing algorithm [5], a new address structure is introduced to indicate that a packet is a broadcast packet. A northbound bit and a southbound bit are extended to a unicast Cartesian packet to signify whether the packet has been sent north, south, or both. Two routing protocols are introduced, one for collector routers and the other for arterial routers; these protocols are separate from the existing unicast routing protocol for Cartesian networks. No changes are required to the unicast protocol, the network.

Other than router modifications to identify broadcast packets, no other changes are required to the network. Source collector routers use the existing unicast Arterial Direction Indicators to start packet transmission. No broadcast specific control information need be exchanged between routers.

When the source router receives a multicast packet from its local port, it sets the destination address of the packet to the unicast address of the AMR and set the "M" field of the packet to "0000" making the packet a unicast packet. Then the source router forwards the packet as a unicast packet. The "MID" field of the packet is the multicast group sequence number. The Multicast Router maintains a table of the membership information for all groups. When a multicast packet arrives at the Multicast Router, the MR looks up its multicast routing table to find the unicast Cartesian address of all members of the destined group. It sends a copy of the packet to the unicast Cartesian address of each group member individually.

The Active Multicast Router (AMR) periodically sends a keep-alive message to the Backup Multicast Router (BMR). The BMR has a timer which is set to the time slightly bigger than the time slot between two keep-alive messages. Each time when the BMR receives a keep-alive message, its timer is reset. If the BMR's timer times out before it receives any keep-alive message, the AMR is considered to be down. Therefore, the BMR sets its flag bit to "1" and broadcasts its unicast Cartesian address to all the routers within the network. The broadcast packet is routed following the Cartesian Broadcast Routing algorithm. Each router keeps the unicast Cartesian address of the new AMR of the whole network. In this way, when the AMR fails, the BMR can change its state to the AMR and keep on processing multicast packets.

3.3 Multicast Extensions to Broadcast Cartesian Routing Protocol

In this protocol, broadcast Cartesian routing technique is deployed in a Cartesian network. The destination address is the group number to which the packet is going to be sent. Each router maintains a list of the group number to which it belongs. When a packet arrives at a router, if the packet is a multicast packet, a copy is kept by the router for further processing. The router forwards the packet following the Cartesian Broadcast Routing algorithm. Additionally, the router checks the destination group numbers specified in the packet and then tries to find those numbers in its own group list. If found, the packet is kept and sent to local hosts through the bottom port of the Multicast Cartesian Router. Otherwise, the packet is discarded. In this way, all destination multicast group members will receive a copy of the multicast packet.

3.3.1 Packet Structure

In this protocol, the multicast packet is derived from a broadcast packet The "M" and "MID" are extended to a broadcast packet. The "M" field indicates whether the packet is a unicast packet (0000), a broadcast packet (0001) or a multicast packet (0010) (See Figure 4 below). The "N" and "S" fields are broadcast routing bits.

M	N	S	MID	DLA	DLO	SLA	SLO	Payload

MEBCR Packet

Figure 4. Structure of the MEBCR Packet

3.3.2 Routing Mechanism

In this approach, broadcast Cartesian routing technique is deployed in a Cartesian network. Four multicast bits are added to each multicast packet. The destination address is the group number to which the packet is going to be sent. Each router maintains a list of the group number to which it belongs. When a packet arrives at a router, the multicast bits of the packet are checked. If the packet is a multicast packet, a copy is kept by the router for further processing. The router forwards the packet following the Cartesian Broadcast Routing algorithm. Additionally, the router checks the destination group numbers specified in the packet and then tries to find those numbers in its own group list. If found, the packet is kept and sent to local hosts through the bottom port of the Multicast Cartesian Router. Otherwise, the packet is discarded.

3.4 Cartesian Geographical Multicast Routing (CGM)

In this approach, a multicast request packet is first routed to the Internetwork Multicast Router (IMR) of the source router's sub-area as a unicast packet. Then it is forwarded to the Encompassing Multicast Router (EMR). The EMR generates a multicast packet and broadcasts the packet to all other EMRs through the multicast network. EMRs then look up their multicast routing tables and send a copy of the packet to each destination group members within their sub-areas in the Cartesian Network. In this way, all destination multicast group members will receive a copy of the multicast packet.

3.4.1 Topology

As shown in Figure 5 below, a Cartesian Network is divided into n sub-areas by grids formed by several horizontal and vertical lines. All horizontal lines are collector lines. The vertical lines need not follow arterial lines, since arterial routers of one arterial do not necessarily have the same longitude. In each sub-area, one arterial router is designed to serve as a sub-source, which is responsible for forwarding multicast packets to all group members within this sub-area using unicast Cartesian routing. A Cartesian Multicast Network is designed to forward any original multicast packets to all sub-sources. Each sub-area is connected to the Cartesian Multicast Network via an Internetwork Multicast Router (IMR) - Encompassing Multicast Router (EMR) link. Being a collector router in the Cartesian Network, an EMR 'encompasses' a sub-area through its bottom port. An IMR is an arterial router in a sub-area, which is responsible for exchanging packets between the EMR and the sub-area [7].

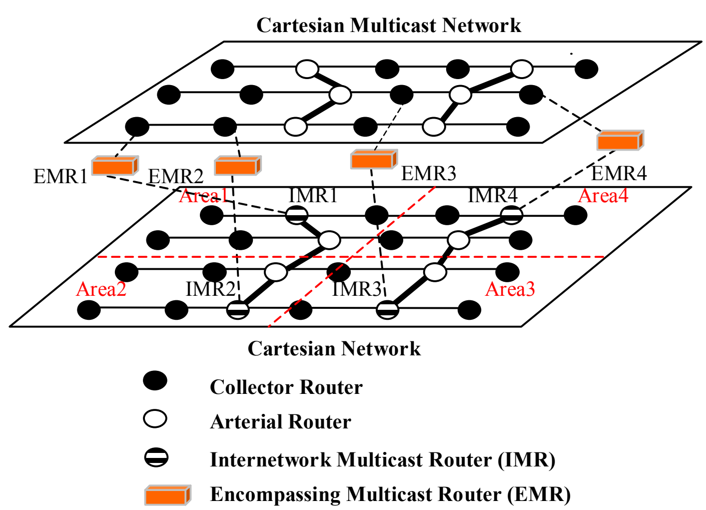


Figure 5 Cartesian Geographical Multicast Routing (CGM).

3.4.2 Packet Structure

In Cartesian Geographical Multicast routing protocol (CGM), two types of packets are introduced. They are CGM multicast request packet and multicast packet. The formats of the two packets are shown in Figure 6 and Figure 7.

M	MID	DQ	DLA1	DLO1	…	DLAm	DLOm	SLA	SLO	Payload

CGM Multicast Request Packet

Figure 6. Structure of the CGM Multicast Request Packet

In CGM multicast request packet (in Figure 6), the "M" field has 4 bits which determines whether the packet is a unicast packet (0000), a broadcast packet (0001), a multicast request packet (0010) or a multicast packet (0011). The "DQ" field means the destination quantity of the packet which has 16 bits. The "DLA1","DLO1", "DLAm","DLOm" indicate the first destination and last destination latitude and longitude. Between them, there may be many destination addresses. "m" is an integer which equals the value of the "DQ" field. The "SLA","SLO" fields indicate the source router's latitude and longitude. The "DLA1","DLO1", "DLAm","DLOm", "SLA","SLO" fields are all 24 bits. "MID" field has 16 bits, which is the multicast group sequece number.

M	MGQ	MID1	…	MIDm	SLA	SLO	Payload

CGM Multicast Packet

Figure 7 Structure of the CGM Multicast Packet

In CGM multicast packet (in Figure 7), the "M" field has the same function as in the multicast request packet described in the previous paragraph. The "MGQ" field signifies the multicast group quantity of the packet which has 16 bits. The "MID1" and "MIDm" fields mean the 1st and last destination multicast group sequence number of the packet. "m" is an integer which equals the value of the "MGQ" field. The "SLA","SLO" fields indicate the source router's latitude and longitude which both have 24 bits.

In order to be routed in the Cartesian Multicast Network, a Cartesian packet should be encapsulated in a multicast packet by attaching a multicast header to it. Each Internetwork Multicast Router (IMR) is connected through its upper port to the bottom port of the corresponding Encompassing Multicast Router (EMR). Each EMR maintains a multicast routing table. The table contains the unicast Cartesian addresses of the group members of each multicast group in the whole Cartesian Network; the group numbers of all multicast groups belonging to the sub-area; the unicast Cartesian addresses of the group members in the sub-area.

3.4.3 Routing Mechanism

In Figure 5, when a source router in the Cartesian network wants to send a packet to more than one destination router, it sends a Cartesian Multicast Request packet to the IMR within its Sub-Area. The IMR then forwards this packet to the corresponding EMR.

When the EMR receives the Multicast Request Packet, it checks the "DQ" field to see how many destinations the packet has. Next, the EMR looks up its multicast routing table to see what groups these destinations belong to. The EMR sends a multicast packet up to the multicast network. The collector router in the multicast network connected to the EMR first checks the "M" field of the packet. If the packet is a multicast packet, it is then forwarded following the Cartesian Broadcast Routing algorithm described in [5]. Through broadcast, every collector router in the multicast network receives a copy of the multicast packet and forwards it to the EMR to which it is connected.

Receiving the multicast packet, each EMR (including the EMR issued the multicast packet) looks up the multicast routing table to see if the sub-area connected to it has members of any group specified in the multicast packet. Then an EMR looks up its multicast routing table to find out the unicast Cartesian addresses of all group members in the sub-area specified in the multicast packet. An EMR then removes the multicast header of the multicast packet, sets the destination address of the Cartesian packet to the unicast Cartesian address of a destination group member in the sub-area and sends the packet to its destination through IMR. In the same way, the EMR sends a unicast Cartesian packet to each destination group member in its sub-area. The times the EMR needs to send out a unicast Cartesian packet are equivalent to the total number of destination group members in the sub-area.

4 RESULTS

Currently, the three Cartesian multicast protocols have been successfully simulated using OPNET Modeler [8]. The simulation implementation and results are presented in this section.

4.1 Simulation Implementation

4.1.1 MEUCR Simulation implementation

4.1.1.1 Routing Algorithm Fragment.

The routing algorithm fragment of the processor of the multicast host of the Active Multicast Router (AMR) of the Cartesian Network is shown below:

1. Get the Multicast type of the Multicast packet.
2. If the packet is a unicast packet or broadcast packet:
   - process unicast or broadcast packet.

   Otherwise

   - Look up the Multicast Routing table and generating a series of unicast Cartesian packets for those routers that belong to the group.

4.1.1.2 Simulation Description.

The above algorithm fragment is the routing algorithm of the processor of the multicast host of the Active Multicast Router (AMR) in a Cartesian Network. In the network, the collector router with unicast Cartesian address (3, 4) is designed to be the

Active Multicast Router (AMR). The collector router with unicast Cartesian address (3, 6) is designed to be the Backup Multicast Router (BMR). Multicast routing tables are maintained by the multicast host of the AMR. The multicast host of AMR is responsible for looking up multicast routing tables, generating a series of unicast Cartesian packets and sending them to all destination multicast group members. Additionally, in the simulation, specific routing algorithms also need to be programmed in collector routers and arterial routers, making it possible for multicast packets to be routed to the AMR.

4.1.2 MEBCR Simulation Implementation

4.1.2.1 Routing Algorithm Fragment.

The routing algorithm fragment of the receiver processor of the west port of an arterial router in the MEBCR network is shown below:

1. Get the Multicast type of the Multicast packet.
2. If the packet is a unicast packet or broadcast packet:
   - process unicast or broadcast packet.

   Otherwise
   - If the router belongs to the multicast group
     -- forward the packet to its local receiver.
   - Forward the packet following Broadcast Cartesian Routing algorithm.

4.1.2.2 Simulation Description.

The above algorithm fragment is the routing algorithm for the west receiver port of an arterial router in the MEBCR network. When a packet arrives at the west port of an arterial router, depending on the value of the northbound bit and southbound bit of the packet and the incoming port, it will be routed either only to the east port or to the north, south and east ports of the arterial router. Additionally, similar algorithms are programmed in other ports of an arterial router and in ports of a collector router.

Receiving a multicast packet, routers first check the "Multicast" field of the packet. If the value of the field is 2, the router checks the destination group numbers specified in the packet and then tries to find those numbers in its own group list. If found, the packet is kept and sent to local hosts through the bottom port of the Multicast Cartesian Router. Otherwise, the packet is discarded.

4.1.3 CGM Simulation Implementation

4.1.3.1 Routing Algorithm Fragment.

The algorithm fragment inside the processor of the local port of a collector router in the Multicast Network in the CGM topology is shown below.

1. Get the Multicast type of the Multicast packet.
2. If the packet is a unicast packet or broadcast packet:
   - process unicast or broadcast packet.

   Otherwise
   - Forward a copy of the packet to the EMR connected to it.
   - Forward the packet following Broadcast Cartesian Routing algorithm.

4.1.3.2 Simulation Description.

The above algorithm fragment is the routing algorithm within the processor of the local port of a collector router in the Multicast Network. When a collector router in the Multicast Network receives a packet from its local port, a copy of the packet is first forwarded to the upper port of the Encompassing Multicast Router (EMR) connected to it. Then, in the multicast network, the packet is forwarded by the collector router following the Broadcast Cartesian Routing algorithm.

In the simulation, two networks are constructed in the network simulation tool OPNET Modeler [8]. One network is the Cartesian Network with six collectors and four arterials. Each collector has eight routers. The other network is the multicast network with two collectors and two arterials. Four Encompassing Multicast Routers (EMR) are set between the two networks. The Cartesian Network is divided into four sub-areas by grids formed by one horizontal and one vertical line. The Unicast Cartesian Routing algorithm [6] is programmed in the nodes of the Cartesian Network. The Broadcast Cartesian Routing algorithm is programmed in the nodes of the Multicast Network. Multicast routing tables are programmed in the four EMRs. Two fields named "IMR_LAT" and "IMR_LON" are created in the attributes of each router in the Cartesian Network. The values of these two fields are set to the unicast Cartesian address of the IMR of its sub-area.

When the source router receives the multicast packet from its local host, it gets the "IMR_LAT" and "IMR_LON" value through special OPNET commands [8], and forwards the multicast packet to the unicast Cartesian address (IMR_LAT, IMR_LON) using the Unicast Cartesian Routing algorithm [6]. All routers on the way of the packet will also get the "IMR_LAT" and "IMR_LON" value and forwards the multicast packet to the unicast Cartesian address (IMR_LAT, IMR_LON) using the Unicast Cartesian Routing algorithm [6]. The IMR forwards the packet to the corresponding EMR. The EMR then checks the multicast routing table and sends a multicast packet up to the multicast network. The packet is broadcasted to all EMRs. EMRs then look up their multicast routing tables and send a unicast Cartesian packet to each destination group member in their sub-areas.

4.2 Multicast Groups Distribution

In the simulation, six multicast groups are constructed. They are shown in Figures 8 – 13 below. The four routers with unicast Cartesian address (6, 2), (6, 8), (3, 8) and (1, 8) form the multicast group No.1 (See Figure 8). This group signifies routers located at the edge area of a Cartesian Network. The three routers with unicast Cartesian address (3, 5), (4, 4) and (4, 5) form the multicast group No. 2 (See Figure 9). This group is located at the central area of the Cartesian Network. The multicast group No. 3 includes routers (1, 5), (3, 5), (4, 5) and (6, 5) (See Figure 10). This group is located within one arterial.

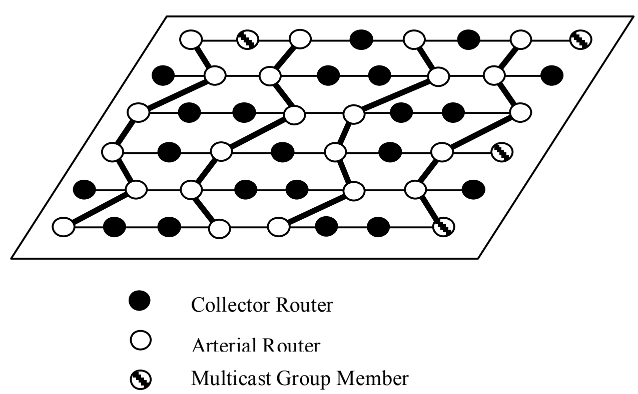
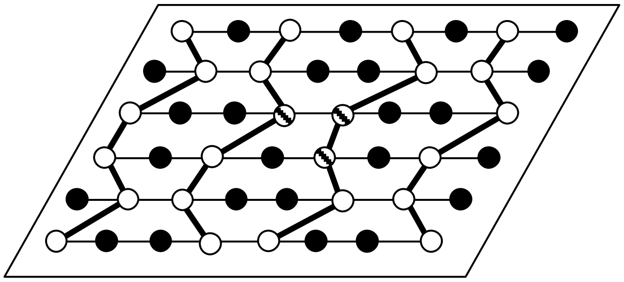
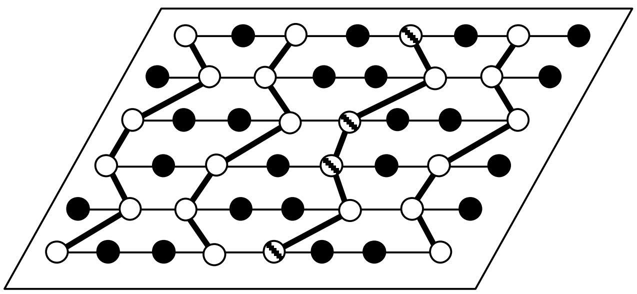


Figure 8. Multicast Group No. 1



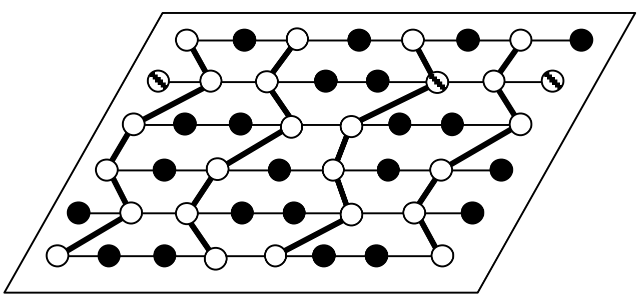
Collector Router
Arterial Router
Multicast Group Member

Figure 9. Multicast Group No. 2



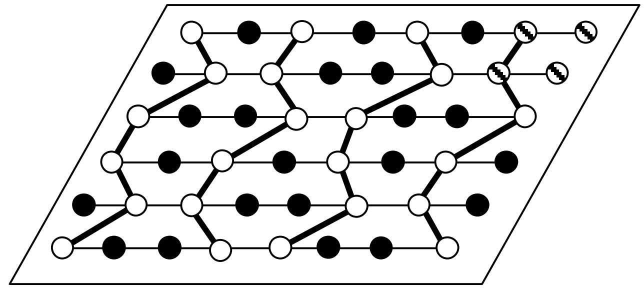
Collector Router
Arterial Router
Multicast Group Member

Figure 10. Multicast Group No. 3



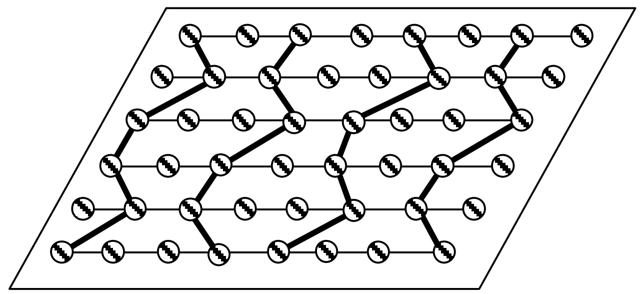
Collector Router
Arterial Router
Multicast Group Member

Figure 11. Multicast Group No. 4



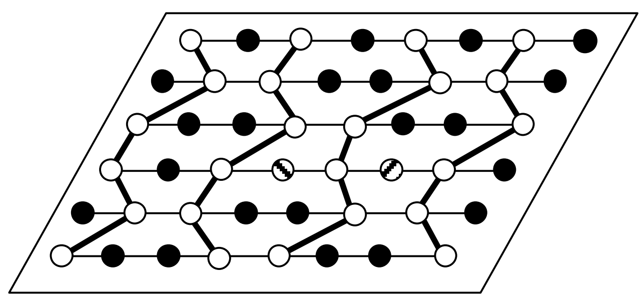
Collector Router
Arterial Router
Multicast Group Member

Figure 12. Multicast Group No. 5



Collector Router
Arterial Router
Multicast Group Member

Figure 13. Multicast Group No. 6



Collector Router
Arterial Router
Active Multicast Router (AMR)
Backup Multicast Router (BMR)

Figure 14. MEUCR Network

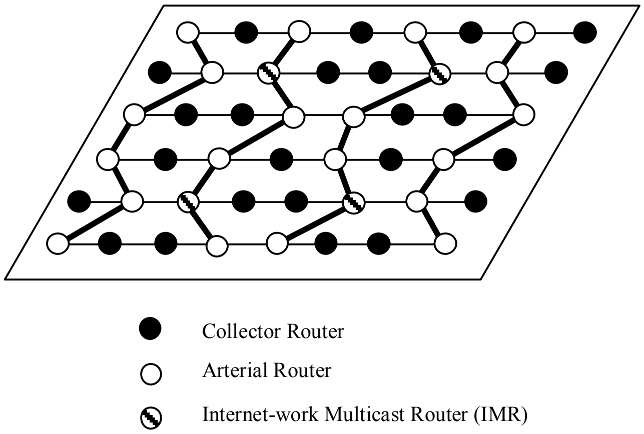


Figure 15. CGM Cartesian Network

The multicast group No. 4 has three routers, whose unicast Cartesian addresses are (5, 1), (5, 6) and (5, 8). This group is distributed on the same collector. Routers (5, 7), (5, 8), (6, 7) and (6, 8) are members of the multicast group No. 5. This group is located at a corner of the Cartesian Network. The multicast group No. 6 includes all routers within the Cartesian Network.

During the simulation, in the MEURC network (See Figure 14), the Active Multicast Router is router (3, 4) and the Backup Multicast Router is router (3, 6). In CGM Cartesian network (See Figure 15), routers (2, 3), (2, 6), (5, 3) and (5, 6) are designed to be the Internet-work Multicast Routers (IMR).

4.3 Test One – The Longest Delay

In this test, the longest delay of the multicast transmission is tested in the three multicast protocols separately. In each protocol, six scenarios are considered corresponding to six multicast groups. The longest delay means the longest transmission time needed to finish the multicast transmission, which signifies the speed of the multicast communication. Therefore, testing the longest delay can unveil the efficiency of a multicast Cartesian routing protocol. The comparison of the longest delay of the three multicast protocols is shown in the Figure 16 below.

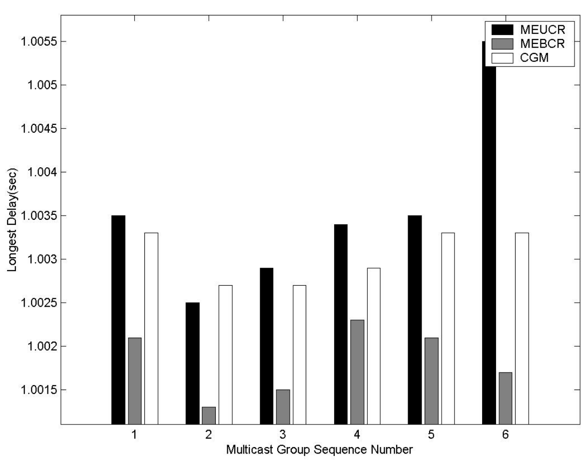


Figure 16. Longest delay of the three multicast protocols.

From Figure 16, we can observe the following. First, in most multicast groups, MEUCR has the largest delay in multicast transmission, which means the transmission speed of this protocol is the lowest in the three multicast protocols. This is because that multicast packets need to be processed and sent to their destination group members by the Active Multicast Router (AMR) one by one, which limits the speed of the multicast transmission, becoming the bottleneck of the Cartesian Network. Second, in all the six multicast groups, the MEBCR needs the smallest delay in multicast transmission, meaning that it is the fastest protocol among the three multicast protocols. Third, in most multicast groups, CGM possesses a medium delay, which means the transmission speed of this protocol is in the middle of the three multicast protocols.

4.4 Test Two – Total Hop Count

In this test, the total hop count is the summation of the times that multicast packets traverse the nodes of the Cartesian Network. Testing the total hop count of three multicast protocols can unveil the traffic load given to the Cartesian Network by each multicast protocol and help us to know the efficiency of different protocols. The total hop count of the three multicast protocols is shown in Figure 17 below.

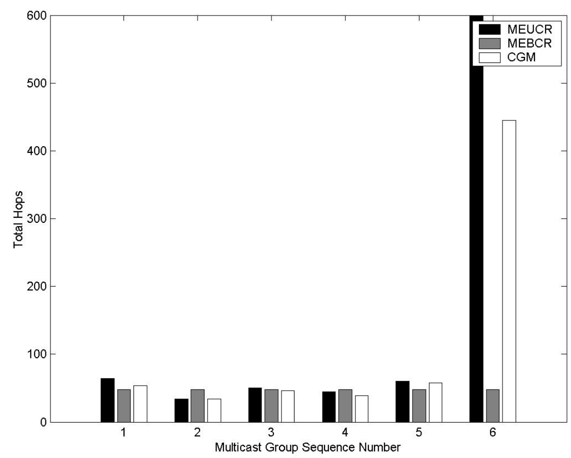


Figure 17. Total hop counts of the three multicast protocols

From Figure 17, we can observe the following. First, for all six multicast groups, the total hop counts of the MEBCR remains the same, meaning that the traffic load given to the network by this protocol is stable, which is because this protocol utilizes the advantage of the Cartesian broadcast transmission. Second, in multicast group No. 6, both MEUCR and CGM have a sudden jump in the total hop counts, which is because these two protocols are both involved in unicast Cartesian routing. From Figure 8 –13 we know that the total number of multicast group members has a sudden increase in multicast group No. 6, which will increase the unicast transmission in MEUCR and CGM dramatically, causing the sudden jump of the total hop counts of these two multicast protocols. Therefore, when large multicast groups are involved in multicast transmission, the price the Cartesian Network needs to pay for MEUCR and CGM will be much higher than that for MEBCR.

4.5 Test Three – Total Processing Time

In this test, the total processing time means the time needed for a multicast protocol to finish processing all multicast transmission. Just because all destination multicast group members have received a multicast packet does not mean the multicast transmission has finished. Some packets may still be traversing on the network. Therefore, it is very important to test the total processing time for different multicast protocols to see the total processing the Cartesian Network has to do for them. The total processing time of the three multicast protocols is shown in Figure 18 below.

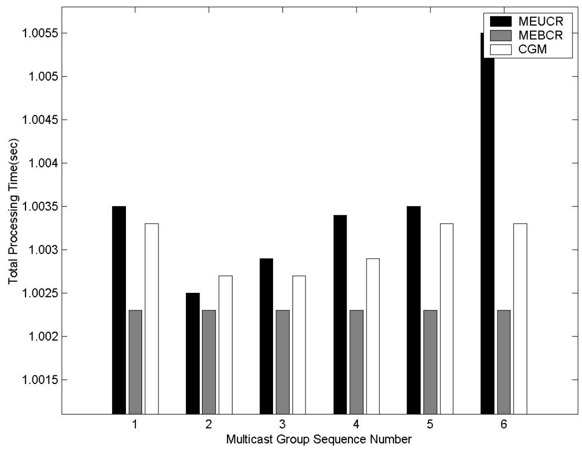


Figure 18. Total processing time of the three multicast protocols

From Figure 18 we can get the following conclusions. First, in all multicast groups, the total processing times for the MEBCR maintain the same and are smaller than the other two protocols. This explains that MEBCR is a stable and efficient multicast Cartesian protocol. Second, in most multicast groups, the total processing times for the MEUCR are the biggest among the three protocols. This is because MEUCR is based upon the unicast Cartesian routing algorithm [6]. Multicast packets need to be forwarded by the Active Multicast Router one by one, increasing the processing time of the Cartesian Network. Third, in all multicast groups, the total processing time for the CGM is comparatively stable. This is because that CGM utilizes the advantages of both unicast Cartesian routing and broadcast Cartesian routing. Multicast packets are processed by many Encompassing Multicast Routers (EMR) simultaneously, increasing the processing speed, thus maintaining a relatively constant total processing time in all multicast groups.

5 CONCLUSIONS

In this paper, the designs of three Cartesian Multicast Routing Protocols (MEUCR, MEBCR and CGM) are discussed and compared. Routing mechanism of each multicast protocol is presented in details. The MEUCR is based on the Unicast Cartesian Routing Protocol [6]. The underlying routing protocol for MEBCR is the Cartesian Broadcast Routing Protocol. By introducing the multicast network, the CGM utilizes the advantage of both the Unicast Cartesian Routing Protocol and the Cartesian Broadcast Routing Protocol.

The three Cartesian multicast protocols have been successfully simulated using OPNET Modeler [8]. Simulation results of them are presented in section 4. Based on the simulation results, in most multicast groups, MEBCR is a stable and efficient multicast Cartesian protocol. The total processing times for the MEUCR are the biggest among the three protocols. The total processing time for the CGM is comparatively stable, which is because that CGM utilizes the advantages of both unicast Cartesian routing and broadcast Cartesian routing.

All in all, by introducing the three Cartesian Multicast Routing Protocols, Cartesian Networks can now fully support Multicast Communication. Therefore, three types of communication are now supported in a Cartesian Network: Unicast Communication, Broadcast Communication and Multicast Communication.

6. REFERENCES

[1] Hee-Sook Shin, Young-Joo Suh and Dong-Hee Kwon, "Multicast routing protocol by multicast agent in mobile networks", Parallel Processing, 2000. Proceedings. 2000 International Conference on , 2000 Page(s): 271 –278.

[2] Uemo, S., Kato, T. and Suzuki, K. "Analysis of Internet multicast traffic performance considering multicast routing protocol ", Network Protocols, 2000. Proceedings. 2000 International Conference on , 2000 Page(s): 95 –104.

[3] Shiwen Chen, Yener, B. and Ofek, Y. "Performance trade-offs in reliable group multicast protocols", INFOCOM '99. Eighteenth Annual Joint Conference of the IEEE Computer and Communications Societies. Proceedings. IEEE , Volume: 2 , 21-25 Mar 1999. Page(s): 982 -989 vol.2.

[4] Te-Chou Su, Jia-Shung Wang, "Buffered multicast routing for video-on-demand systems", Communications, 1999. ICC '99. 1999 IEEE International Conference on , Volume: 2 , 1999 Page(s): 1000 -1004 vol.2.

[5] Larry Hughes, "Broadcast Communications in Cartesian Networks", submitted to the journal "Computer Networks", December 2002.

[6] Larry Hughes, Omid Banyasad and Evan Hughes, "Cartesian Routing", Computer Networks, vol. 34, pp 455-466, 2000.

[7] Larry Hughes, Omid Banyasad and Evan Hughes, "Wide Area Cartesian Routing", June 2001.

[8] OPNET Technologies, Inc, "Online Documentation for OPNET Modeler 9.0", 1999-2002.