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An All-to-All Multicast Routing Protocol in a Wireless Ad-Hoc Network to Improve Channel Utilization

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AN ALL - TO - ALL MULTICAST ROUTING PROTOCOL
IN A WIRELESS AD - HOC NETWORK TO IMPROVE
CHANNEL UTILIZATION

Zhong - Hua Zhou



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Columbus State University

The College of Science

The Graduate Program in Computer Science

AN ALL-TO-ALL MULTICAST ROUTING PROTOCOL
IN A WIRELESS AD-HOC NETWORK TO IMPROVE CHANNEL UTILIZATION

A Thesis in

Computer Science

by

Zhong-Hua Zhou

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

May 2001

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I have submitted this thesis in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

ALL-TO-ALL MULTICAST ROUTING PROTOCOL
IN A WIRELESS AD-HOC NETWORK

Zhong-Hua Zhou, M.S.

Columbus State University, 2001

Supervising Professor: Seong-Moo Yoo

Wireless Ad-hoc network has become more and more popular. Several different multicasting schemes for this type of network have been developed. But most of them are targeting a situation where the total number of senders is much less than the total number of receivers. This thesis analyzes different wireless communication patterns in ad hoc network, the trend for wireless communication and presents a new multicast scheme. It targets an ad-hoc network where all mobile hosts act as both senders and receivers. The proposed scheme in this thesis will reduce overheads by combining data packets that are destined for the same mobile hosts. The action of combining jobs will be done at mobile hosts which are not joined in the multicasting group and only functioned as forwarders.

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CHAPTER 1

INTRODUCTION

1.1 Background

All-to-All communication pattern can be found in conferences and meetings in wireless ad hoc networks. Today, people attend meetings and conferences with laptops, notebooks and other types of PDAs. It is therefore attractive to have instant network formation, in addition to file and information sharing, without the presence of fixed base stations and system administrators. The topology of an ad hoc network can be very dynamic due to the mobility and the characteristics of radio channels. Network hosts in ad hoc networks are equipped with packet radios for communications between one another.

With multicasting, audience members can not only communicate with the presenter as in broadcasting but also with each other and exchange information.

This thesis has developed a multicast routing algorithm for all-to-all communication in wireless ad hoc networks. Rather than conventional tree-based routing protocol, All-to-All Multicast Routing Protocol (ATAMRP) is a mesh-based multicast scheme using a forwarding group concept and a combining data packets at forwarding nodes concept. Computer simulation has been done using the simulator implemented within the Global Mobile Simulation (GloMoSim).

1.2 Goal

This thesis has the goal of designing a wireless ad-hoc network multicast scheme which has an all-to-all communication on which the overheads will be reduced. This thesis has the following objectives:

- 1) To analyze previous wireless ad-hoc network multicast schemes.
- 2) To propose an all-to-all communication scheme for wireless ad-hoc network with a combining data packets at forwarding nodes concept.
- 3) To compare the proposed scheme with previous scheme.

1.3 Organization

In Chapter 2, several data communication patterns are presented including one-to-one, broadcast, and all-to-all patterns. In Chapter 3, a brief history of wireless communication is presented followed by several previous ad hoc schemes. Chapter 4 will present a simple communication traffic scenario and explain how traffic goes. Two enhancements to routing performance and algorithm will be presented. There will be a simulation after that in Chapter 5. Chapter 6 will conclude this thesis.

CHAPTER 2

COMMUNICATION PATTERNS

Communication operations can be either one of two major groups: *Point-to-point*, with one source (sender) and one destination (receiver), and *collective*, with more than two participating processes [1]. Collective operations are invoked by nodes to gather, distribute, and exchange data; to perform computation operation on distributed data; and to synchronize with each other at certain points in the program process. Collective operations are classified into three types according to their purpose: data movement, global computation, and process control. I am going to focus on the operation of data-movement. There are several different types of data-movements.

2.1 One-to-One Communication Pattern

Figure 1 shows a simple one-to-one operation. The oval shaped circle represents a process. The word *process* and *node* are interchangeable in the data-movement part. The rectangle represents a data item. The solid line arrow represents a message sending.

In Figure 1, Process 1 sends a single data item (message) to Process 2 only. In a wireless communication situation, only Process (Node) 2 will process the message even though other processes or nodes might receive the message as well.

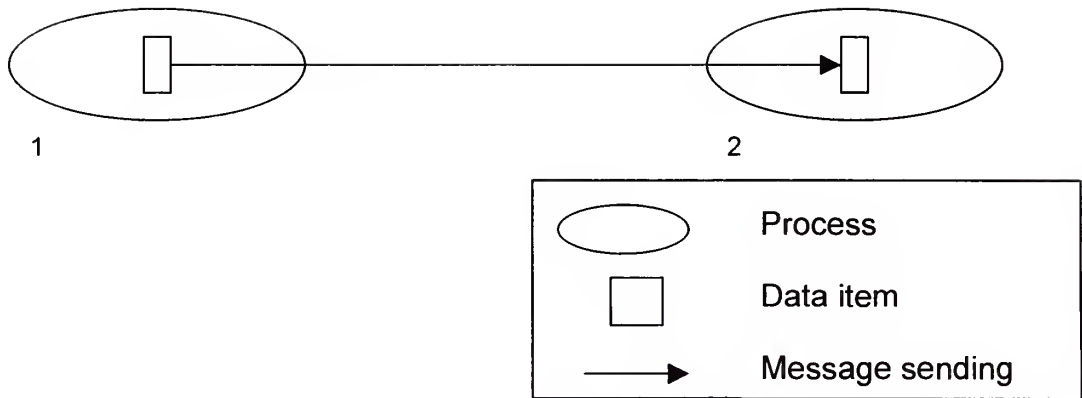


Figure 1. One-to-one communication from Process 1

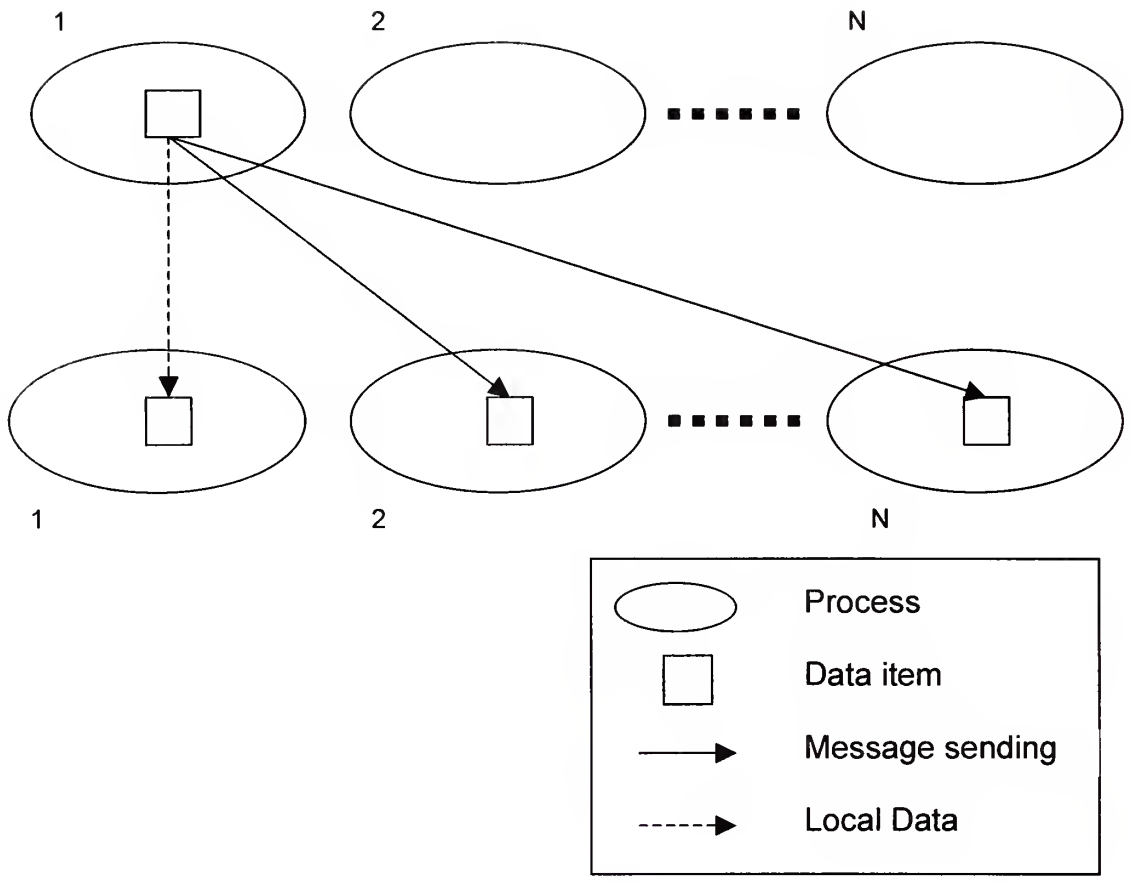


Figure 2. Broadcast from Process 1

2.2 Broadcast Communication Pattern

Figure 2 shows a broadcast communication pattern. A broadcast involves all nodes in the network. In wireless communication, all nodes that can hear the message are involved. There will only still be a single message. There exist only one sender and multiple receivers.

The solid line arrow in Figure 2 represents message sending. The dashed line arrow represents local data. Message from Process 1 is sent to Process 2 through Process N. Each process will receive one copy of data item generated by Process 1.

2.3 All-to-All Communication Pattern

Figure 3 shows an example of all-to-all communication pattern. It is like putting several broadcast communications into one big group. In all-to-all communication, the number of senders is equal to the number of receivers. Each sender also acts as a receiver.

Sometimes, this type of communication is referred as multicasting. Several different multicasting protocols have been developed. And new ones are still being developed. Most of multicasting protocols are targeting at a situation where the number of senders is less than the number of receivers.

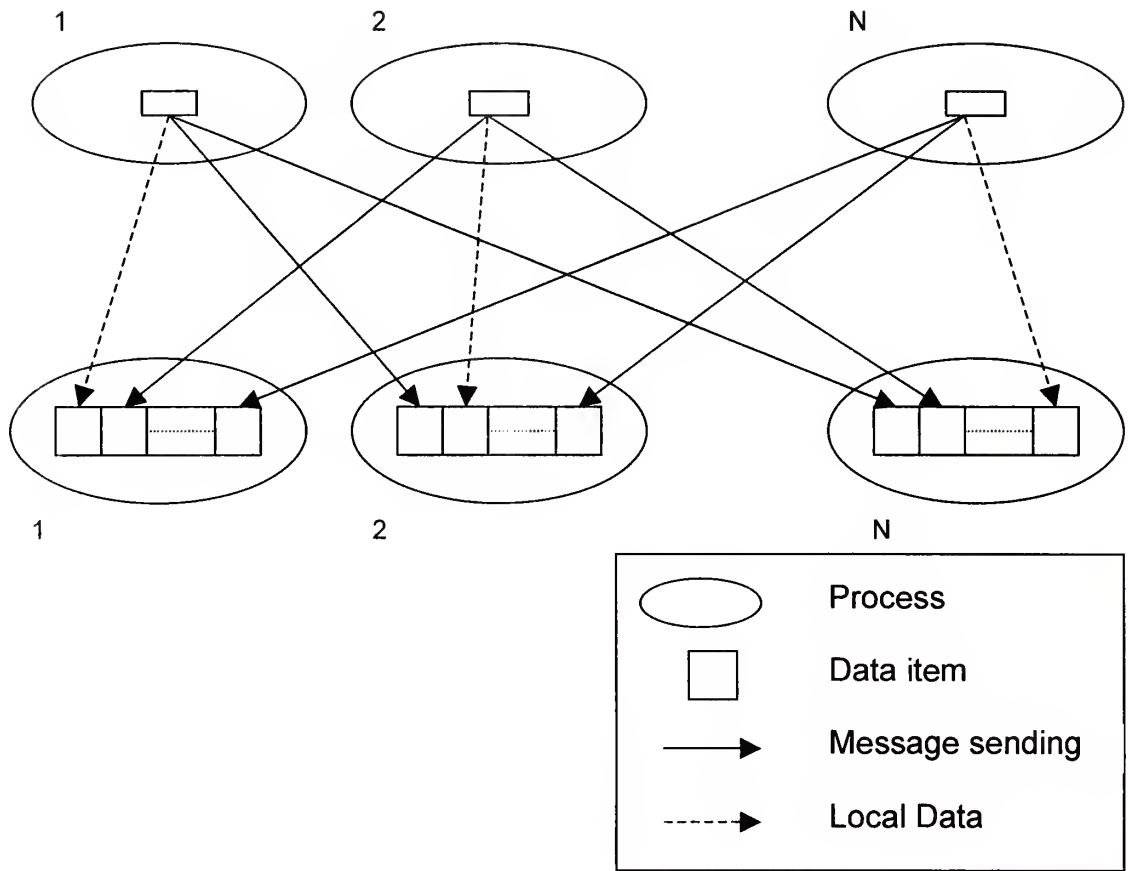


Figure 3. All-to-all communication pattern

CHAPTER 3

WIRELESS COMMUNICATION

The primary goal of developing the all-to-all communications in wireless ad hoc networks is to reduce overhead. In this chapter, several issues will be discussed, including the evolution of wireless network, what ad hoc wireless network is, and a few previous schemes.

3.1 The Evolution of Wireless Network

At the beginning of the computer age, there exists only a wired network. To communicate with each other, the computers are connected through wire which can be made of anything that can let electricity to go through. The most popular material used is copper because of its extremely high conductivity of electricity, which is second only to that of silver [5]. With this wire, a lot of things have been connected together. Local Area Networks (LANs) connect computers separated by short distance, such as in an office or university campus. Wide Area Networks (WANs) connect distance equipment across city, country or even internationally. The Internet, probably the most popular network, is composed of a large number of smaller interconnected networks called internets. Unlike traditional broadcasting media, such as TV and radio, the Internet is a decentralized system [5]. Anyone connected to the Internet can communicate with anyone else. The problem with wired network is that it has to use wire, either through network set up in their office or a telephone line; therefore user mobility is limited. Mobility means that a user has access to the same or similar

telecommunication services at different places [6]. It is partially because of device portability. With wired network, computers or other devices cannot be moved while being used.

Many people are mobile now. It is already one of the key characteristics of today's society. Numerous wireless devices have been developed. PDAs (Personal Digital Assistants) are very popular today. PDAs are used mainly for taking notes and scheduling appointments. Many PDAs can connect to other computers, either through telephone lines, radio waves or a computer cable. More and more people have laptops or other types of portable computers. Electromagnetic waves are replacing the wire. There is a big need of wireless networks.

To better understand today's wireless systems and developments, a short history of wireless communication is presented in the following section.

The use of light for wireless communications goes back to ancient times. The use of smoke signals for communication was mentioned by Polybius, a Greek historian, as early as 150 BC [6]. Chinese probably used smoke signal before that to communicate between the towers of the Great Wall.

The idea of wireless radio communications arose in the mid-1800s from the theories of two English physicists, Michael Faraday and James Clerk Maxwell. It all started when Michael Faraday demonstrated electromagnetic induction in 1831 and James Maxwell laid the theoretical foundations for electromagnetic fields with his famous equations (1864) [6]. Heinrich Hertz

demonstrated through an experiment the wave character of electrical transmission through space in 1886. Guglielmo Marconi is probably the one who is the most closely connected with the wireless communication. In 1895, he demonstrated wireless telegraphy by using long wave transmission with very high transmission power (> 200 kW). Short wave was discovered in 1920, again by Marconi. The technique is still used today.

Many national and international projects in the area of wireless communications were triggered off after the World War II. The first generation of wireless communication was the analog system. The early 1990s can be marked as the beginning of fully digital systems. Though data communication is supported, second generation of wireless communication is mainly in voice communication. The third generation happens now. It will fully support digital data communication as well as voice communication. The main goal for the fourth generation is to have a global standard, international roaming, for anybody, from anywhere, at anytime.

3.2 Market for Mobile Communications

More and more people use mobile phones. Many cars have built-in wireless technology, wireless data service can be accessed from many regions, and many places have wireless local area networks. Looking at the current growth rate in wireless communication shows the huge market potential of these technologies.

Most of these situations require an infrastructure network. Besides providing access to other networks, infrastructure networks provide forwarding functions, medium access control. In these types of networks, communication typically takes place only between the wireless nodes and the access point but not directly between the wireless nodes. A communication device will most likely fall into one of the following categories:

- Fixed and wired: The typical desktop computer in an office will fall in this configuration.
- Mobile and wired: Functionality of many of today's laptops fall into this category. People carry their laptops while traveling and reconnect to company's network via a modem.
- Fixed and wireless: Can be used to avoid damage by installing networks in historical buildings or at trade show to ensure fast network setup.
- Mobile and wireless: User is not restricted by cable. User can roam between different wireless networks.

These infrastructure-based networks lose some flexibility, e.g. they cannot be used for disaster relief where perhaps no infrastructure is left. Also, for a 2-3 day conference, it's not cost-efficient to build any infrastructure-based networks. In those cases, a network without infrastructure is a better choice.

This type of network is usually referred to as an ad hoc network. An ad hoc network is a wireless network that is dynamically reconfigurable with no fixed infrastructure. Each node can communicate with another node. No access point

is needed. Nodes within a particular ad hoc network can only communicate if they can reach each other physically, i.e., if they are within radio range of each other or if other nodes can forward the message. Routes are often "multihop" because of the limited radio propagation range of wireless devices. Nodes that are for forwarding purpose only are referred to as forwarders. Most nodes have the functionality of forwarding data. Some join the multicasting group and become a sender or receiver or both; some only act as forwarders. Ad hoc networks may only select nodes with the capabilities of forwarding data [6]. Most of the time, nodes will have to connect to a special node first in order to send data if the receiver is out of their radio transmission range.

For example, in Figure 4, N_2 can communicate with N_1 , N_4 and N_5 directly because they are within radio range of N_2 . N_2 can also communicate with N_3 through N_5 , which acts as a forwarder to forward messages between these two nodes. N_1 can communicate with N_3 via different routes, one being N_1 , N_4 , N_5 and N_3 .

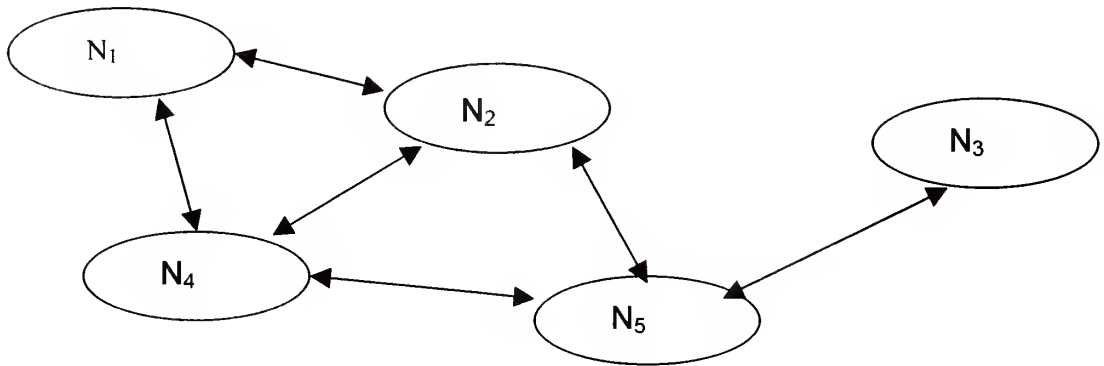


Figure 4. An example of ad hoc network

There are several situations where users cannot rely on an infrastructure; the infrastructure is too expensive, or an infrastructure does not exist at all. Ad hoc networks are the only choice in these situations. Below are some examples for the use of ad hoc networks:

- Instant infrastructure: Unplanned meetings. cannot rely on any infrastructure. Infrastructures need planning and administration.
- Disaster relief: In disaster areas, infrastructures typically break down. Hurricanes destroy phone and power lines, floods destroy base stations, fires burn server equipment. Emergency teams can only rely on a network they can set up themselves and the setup must be done really fast.
- Remote areas: Sometimes, it is too expensive to set up an infrastructure in a remote, low population area even if infrastructures could be planned ahead.

3.3 Routing Issues in Ad Hoc Network

Routing of data is one of the most difficult issues in ad hoc networks. Advanced Research Projects Agency of the U.S. Department of Defense started the first ad hoc wireless network, which was a packet radio network, in 1973 [6]. It used IP packets for data transport and allowed up to 138 nodes in the ad hoc network. Twenty radio channels between 1718.4-1840 MHz were used offering 100 or 400 kbit/s. A variant of distance vector routing was used in this ad hoc

network. Every 7.5 seconds, a routing advertisement was sent by each node. A neighbor table with a list of link qualities was included in these advertisements. A distance vector algorithm based on these advertisements was used to update each node's local routing table. A sender transmitted a packet to its first hop node using the local routing table. When a node received a packet, it forwarded the packet based on its own local routing table if itself were not the destination. Several enhancements are needed to avoid routing loops and to reflect the fast changing topology. In wireless networks with infrastructure support, a base station always reaches all mobile hosts. This is not always true in an ad hoc network. A destination node might be out of range of a source node that is transmitting packets. Routing is needed to find a path between source and destination. In an ad hoc network, each node must be able to forward data for other nodes.

Figure 5 and Figure 6 show simple examples of an ad hoc network. At a certain time, t_1 , the network topology, might look as illustrated in Figure 5. In this snapshot of the network, the two links between N_1 and N_4 do not necessarily have the same characteristics in both directions. One might have better transmitting quality than the other. This is referred to as asymmetric links. One link might receive nothing or have a weaker link. In an ad hoc network, nobody controls redundancy, so there might be many redundant links. For example, in Figure 5, N_2 can send packets to N_5 directly or via N_3 . Interference is another problem. One transmission might interfere with another, and nodes might

overhear transmissions of other nodes. The greatest problem for routing is probably the dynamic topology. The mobile nodes might move around and medium characteristics might change. Snapshots are only valid for a very short period of time.

At anytime, the snapshot in Figure 5 might change to t_2 in Figure 6. Now the direct link between N_2 and N_5 is lost. N_2 still can send packets to N_5 via N_3 but N_5 can not use the same route to send reply or other data packets to N_2 because the link exists in only one direction. N_5 can still send packets to N_2 through other routes. It can use N_4 and N_1 as forwarding nodes to reach N_2 .

Using standard routing protocols with periodic updates wastes battery power without sending any user data. Periodic updates also waste the already scarce bandwidth resources of wireless links. Traditional routing algorithms adapted from wired networks will not work efficiently or fail completely. These algorithms have not been designed with a highly dynamic topology or with other ad hoc network characteristics in mind.

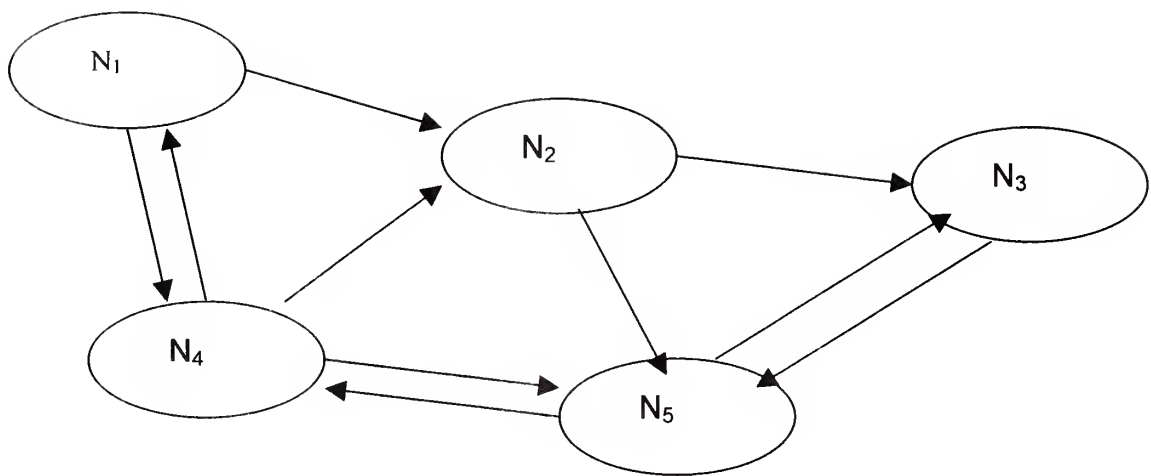


Figure 5. An example of an ad hoc network at a time t_1

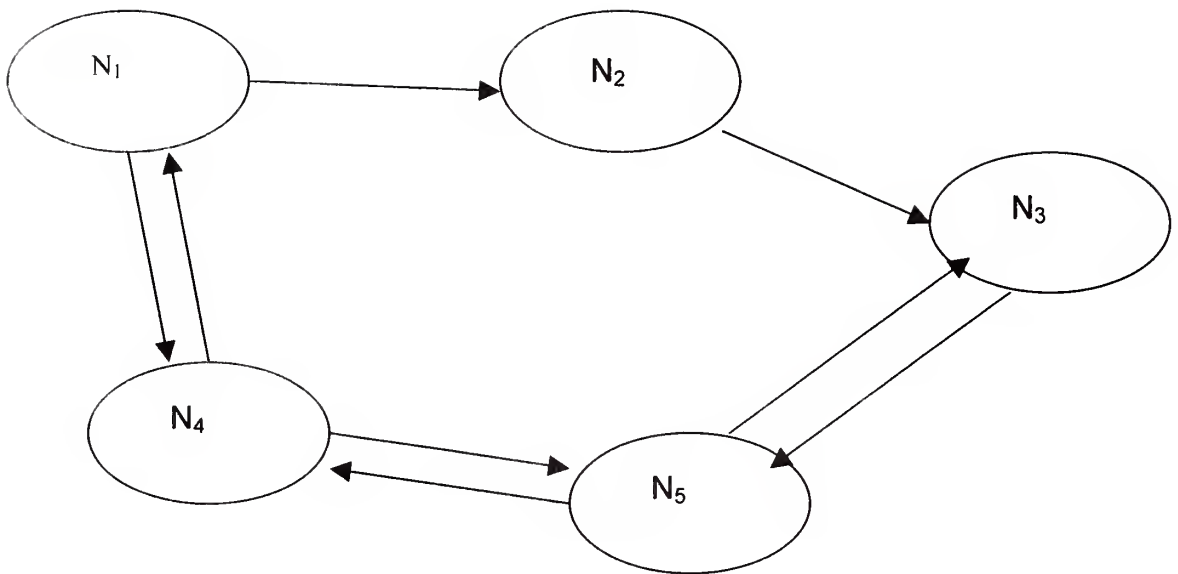


Figure 6. An example of an ad hoc network at a time t_2

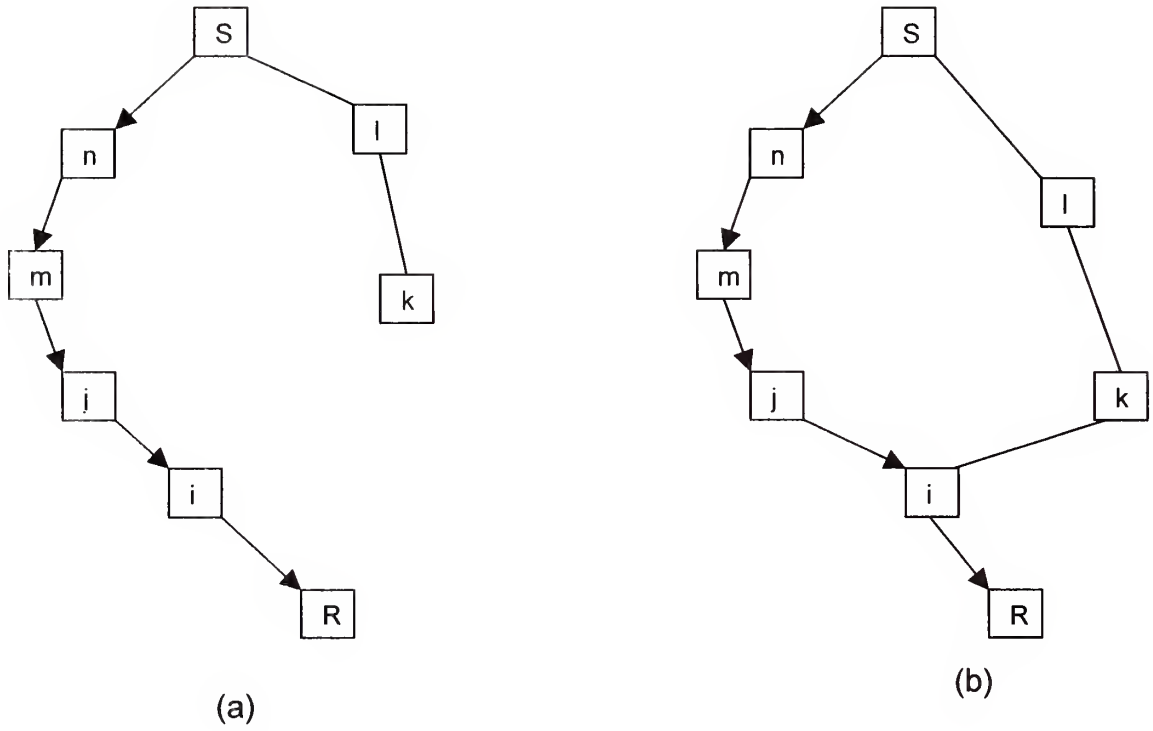


Figure 7. An example of upstream change

3.4 Previous Multicast Routing Protocols

The following sections explain several examples of previous multicast routing protocols. The Distance Vector Multicast Routing Protocol (DVMRP) [7, 12, 13] is the most commonly used multicast routing protocol in the Internet Mbone and is extended to mobile wireless networks. The Mbone, or multicast backbone, is just a fancy name. It is at best a temporary utility that will eventually become obsolete when multicasting is a standard feature in Internet routers [15]. Most of traditional routers used in the Internet have been unicast routers that cannot handle multicast data packets. The Mbone allows multicast packets to travel through routers that can only handle unicast traffic. Software that utilizes Mbone puts multicast packets in traditional unicast packets so that unicast routers can handle the information. The technique of moving multicast packets by putting them in unicast packets is called tunneling. When multicast feature becomes standard, all these overheads of tunneling will be avoided. The DVMRP is derived from Routing Information Protocol [16]. DVMRP was not developed for use in routing non-multicast packets, so two separate processes, multicast and unicast, must be implemented if router routes both multicast packets and unicast packets. The multicast forwarding algorithm in DVMRP requires the building of trees based on the routing information. The DVMRP constructs delivery trees based on the information on the previous-hop back to the source. It keeps track of the return paths to the source of the multicast packet. This mechanism is called Reverse Shortest Path Forwarding (RPF). Packets are accepted only from

the shortest path. In an ad hoc wireless network, topology can change very frequently. It is possible that the multicast traffic stops due to upstream link change. For example, in Figure 7, the multicast route from source S to receiver R is $S \rightarrow n \rightarrow m \rightarrow j \rightarrow i \rightarrow R$. The RPF will work just fine at this moment. But when the topology changes from Figure 7(a) to 7(b), node i will not accept packets from j but from k (the new shortest path), however, there is no traffic coming from k because l and k are not forwarding any packets from S. Reflooding is needed to correct this situation and establish the new multicast route $S \rightarrow l \rightarrow k \rightarrow i \rightarrow R$. Upstream nodes may change or be disconnected due to node mobility. It is necessary to re-flood the network in order to reestablish the upstream information, reconnect lost members, or allow new members to join. It is also needed to confirm the existence of the sender source. This periodical reflooding causes very large transmission overhead especially in a low bandwidth wireless channel. In DVMRP, each sender uses flooding to direct the multicast packets to all nodes. The packets used in flooding carries actual data, which is very large in size.

Destination Sequence Distance Vector (DSDV) routing is an enhancement to distance vector routing for ad hoc networks [6, 8]. It is derived from a distance vector algorithm, Distributed Bellman-Ford (DBF) algorithm. It is well known that this DBF algorithm can cause the formation of both short-lived and long-lived loops [9]. Enhancements are made in order to avoid the looping problem presented in the basic DBF. The DSDV protocol allows a collection of computers

without any base station (ad hoc network) to exchange data. It also remains compatible with operation in cases where a base station is available. Formation of loops is avoided by tagging each route table entry with a sequence number to order the routing information. Packets are transmitted between the stations of the network by using routing tables which are stored at each mobile host of the network. Each routing table contains all available destinations, and the number of hops to each. Each routing table entry is tagged with a sequence number which is originated by the destination station. Each host periodically transmits updates and transmits updates immediately when significant new information is available. Routing information is advertised by broadcasting or multicasting periodically. The sequence number is attached to routing advertisement. Sequence numbers help to apply the advertisements in correct order. Upon receiving a route update packet, each mobile host compares it to the existing information regarding the route. Routes with old sequence numbers are simply discarded. The routing table also has another parameter called *metric*. It is a hop count. In case of route with equal sequence number, the advertised route replaces the old one with the one with better metric. One of the major advantages of DSDV is that it provides loop-free routes. It also has few drawbacks. DSDV uses both periodic and triggered routing updates, which could cause excessive communication overhead. In addition, a node has to wait until it receives the next route update originated by a destination before it can update its routing table entry for that particular destination.

Traditional multicast protocols based on upstream and downstream links (like DVMRP) are not suitable for a wireless network because creating and maintaining upstream and downstream link status is not efficient here. Multicast forwarding is based on mobile hosts (routers) which are going to accept multicast packets, not on links on which multicast packets are forwarded. . Forwarding Group Multicast Protocol (FGMP) [12, 14] utilizes the concept of forwarding group and the use of flags. FGMP keeps track of groups of nodes which participate in multicast packets forwarding. Each multicast group G is associated with a forwarding group, FG. Any node in FG can forward a multicast packet of G if it is not a duplicate. It does this by broadcasting the packet. All neighbors within radio transmitting range can hear it, but only mobile hosts that are in FG will check for duplication and then broadcast it in turn. This scheme can be considered as "limited scope" flooding. That is, flooding is contained within a properly selected forwarding group. Each forwarding node needs only one flag and a timer. The forwarding flag is associated with a soft state timer. The flag is maintained as soft state, which means that it has to be reset before time expires. Senders will need full membership or routing information before they can send any data. In a wireless network, topology changes very frequently and no long term or permanent routing information will be valid after the changes. Thus some limited flooding is required to discover and update members. Instead of flooding data packets like DVMRP, FGMP only flood small size control messages and

with less frequency. Its membership advertising scheme only refreshes the membership. Channel overhead is lower than protocols using data packets to do global flooding like DVMRP. FGMP has two ways of advertising membership. One is to let each receiver flood its member information periodically and globally. Then, the sender of the group collects all the membership information and builds a forwarding table with all the receiver members of the group and corresponding next hop node listed. Receiver entries that are expired will be deleted from the member table. The sender will broadcast multicast data packets only if the member table is not empty. The sender creates the forwarding table after updating the member table. The forwarding table is forwarded to the next hops toward each receiver. The next hop information is extracted from preexisting routing tables. The next hops again forward the table to their next hops toward the receiver members. Forwarding tables are not stored like routing tables. They are created and broadcast to the neighbors only when new forwarding tables arrive. When new forwarding tables arrive, their forwarding timers will be refreshed. The forwarding node will be deleted from FG and flag will automatically time out if the timer is not refreshed. Another way of advertising membership is to do everything in reverse order. Senders will flood sender information and receivers collect information. The forwarding group is maintained by the senders in a receiver advertising scheme and by the receivers in a sender advertising scheme.

On-Demand Multicast Routing Protocol (ODMRP) [11] is a multicast routing protocol designed for ad hoc networks with mobile hosts. It is a mesh-based multicast scheme and uses a forwarding group concept to build a forwarding mesh for each multicast group just like in Forwarding Group Multicast Protocol. As the title suggested, it uses on-demand procedures to dynamically build routes and maintain multicast group membership. A mesh based multicast scheme will avoid the drawbacks of multicast trees in mobile wireless networks, i.e. frequent tree reconfiguration, traffic concentration. ODMRP is an on-demand protocol, thus it does not maintain route information permanently. Group membership and multicast route are established and updated by the source on demand. When a multicast source has data packets to send but no route and group membership information, it originates a "Join Query" packet. This packet is a member advertising packet. It will be flooded. It will have no user data payload in it. It has source IP address, the last hop IP address sequence number and data type fields among others. The source IP address and last hop IP address will be the same when the source node first generates the packet. When a node receives a Join Query packet, it will check to see whether it's a duplicate. It does so by comparing the combination of source IP address and sequence number with the entries in its own message cache. If it's not a duplicate, it will update its message cache and update the entry for a routing table of its own. It then broadcast the received packet with a newly updated routing table. When the packet reaches a multicast member (receiver), the receiver creates a Join Reply

packet after selecting the multicast route. The packet will include sender IP address and next hop IP address. When a node receives a Join Reply packet, it will compare the next hop IP address field of the received Join Reply entries with its own IP address. If its own IP address doesn't match any of the entries in the received Join Reply packet, it does nothing. This is because in a wireless network, all neighboring nodes can hear a broadcast. If all nodes rebroadcast packets after they heard it, the network would be congested and many packets would be in loops. This way, only the intended node will process the packet and rebroadcast. If the next hop IP address matches its own IP address, the node realizes that it's on the path to the source and is part of the forwarding group. It will set the FG_FLAG and generate its own Join Reply. It will extract the next hop IP address from the routing table. It then broadcasts Join Reply packet. The Join Reply packet is thus propagated by each forwarding group member until it reaches the multicast source. Each multicast sender sends Join Query periodically to refresh the membership information and update the routing information. The user data transfer procedure is pretty simple. Multicast sources send packets whenever they have data to send. Nodes will forward the data if the setting of FG_FLAG has not expired and the data is not a duplicate. The ODMRP can coexist with other unicast routing protocol and it can also operate alone as unicast routing protocol. No explicit control message transmission is required to leave the multicast group. ODMRP requires periodic flooding of Join Requests to build and refresh routes.

CHAPTER 4

ALL-TO-ALL MULTICAST ROUTING PROTOCOL IN WIRELESS AD-HOC NETWORKS

4.1 Introduction

An ad hoc network is a dynamically reconfigurable wireless network without any base station or fixed infrastructure that can be deployed instantly. Multicast plays an important role in ad hoc networks. Multicast routing protocols developed for static networks such as DVMRP do not perform well in ad hoc networks. Continuous topology changes and channel overhead are probably the two most challenging fields. There exist some other physical limitations like limited bandwidth and constrained power.

Several multicast protocols have been proposed. These routing protocols can be classified into two categories [17]: (1) proactive, which is distance or link state based like DVMRP, and (2) reactive, which is on demand like ODMRP. The trend of ad hoc network multicast protocol is in favor of reactive or on demand style. In these “reactive” protocols, a node discovers a route “on demand”; it computes a route only when needed.

While different routing protocols are being developed, they all have same goal – making packet delivery faster and more accurate. There exist two types of overheads: channel overhead and storage overhead. Storage overhead is mostly related to the hardware part of the network. Many mobile computers today have resources large enough to handle storage overheads. Channel overhead is any

non-user data packet that is being sent through a radio channel. It is very important to reduce the channel overheads.

In this section, an all-to-all multicast routing protocol for an ad hoc wireless network is proposed and, the protocol will be compared with ODMRP.

4.2 Scenario

For most multicast routing protocols, a source will initiate the joining procedure since the source knows that it needs to join the multicast group in order to send user data to other members in the group.

Let us consider Figure 8 for the whole communication process from Join Request to user data transmission. Nodes S_1 and S_2 are multicast sources. Nodes R_1 and R_2 are multicast receivers. Node A, B, and C are forwarding group members. Node S_1 has data to send but no routing information is available. Thus, it broadcasts a Join Request to everyone within its radio range. Node A (a member of forwarding group) will rebroadcast the message after receiving it and checking for duplication. After this, node B, C and S_2 will hear the message but only B and C will process the message and rebroadcast it. S_2 is not processing it because S_2 is not a member of the multicast group yet. The same thing happens to S_1 when S_2 broadcasts its Join Reply message. When the Join Reply message reaches any multicast receivers, they will generate a Join Reply message with source node's address as destination. At the same time, a new routing table will be generated as well according to the algorithm defined in their routing protocol. The Join Reply message will propagate through forwarding group and reach

source nodes. Nodes along the way will create and/or update their routing information. The source node will start transmitting user data after receiving the Join Reply message.

Table 1 shows timings generated by ODMRP's algorithm. The sequence of time slots is in order and the lengths of each time slot are not necessarily equal. Only the transmitting (outgoing) packet is listed. The action of the receiving (incoming) message is not listed to save space. The format of message in this table, e.g. DPS1R2ii, is explained as follows. The first two characters are data type, Join Query, Join Reply, or User Data. The 3rd/4th characters are source node address. The 5th/6th characters are destination node address. The sequence ID of the message follows that. The table is generated after two source nodes have completed transmission of second user data packet. It stops there to save space.

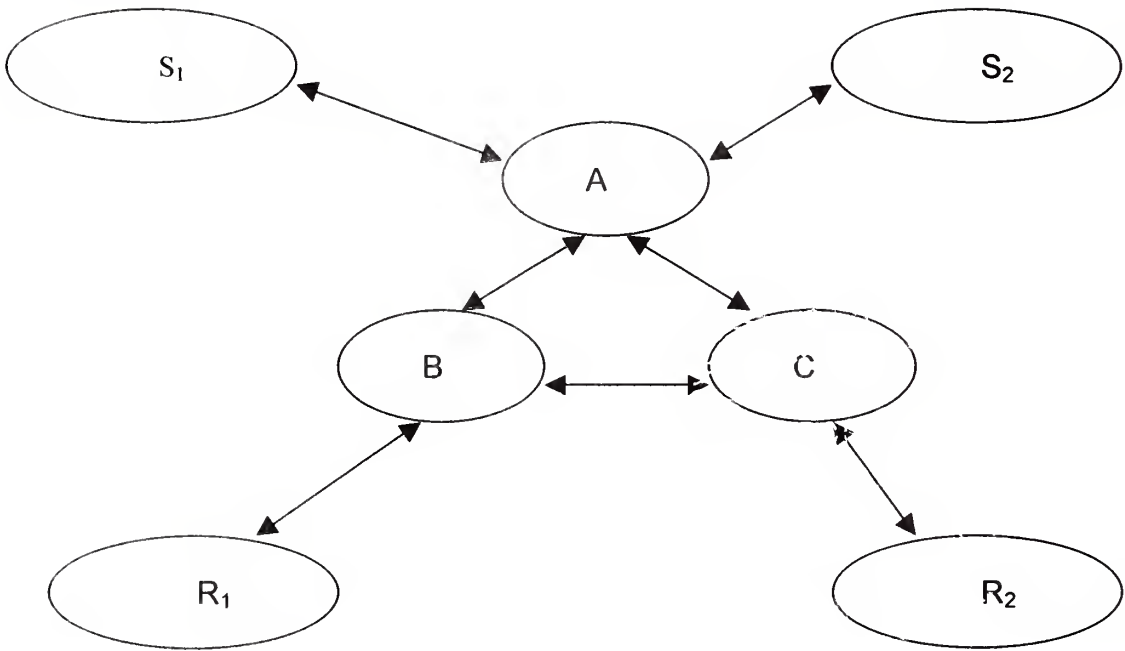


Figure 8. An example of communication scenario

Table 1. A timing table for ODMRP

	S1	S2	A	B	C	R1	R2
T1	JQS1	JQS2					
T2			JQS1				
T3			JQS2	JQS1	JQS1		
T4				JQS2	JQS2	JRR1S1	JRR2S1
T5				JRR1S1	JRR2S1	JRR1S2	JRR2S2
T6			JRR2S1	JRR1S2	JRR2S2		
T7	DPS1R1i		JRR2S2				
T8	DPS1R2i		JRR2S2				
T9	DPS1R2ii	DPS2R2i	JRR1S2				
T10	DPS1R1ii	DPS2R1i	DPS1R2i				
T11		DPS2R2ii	DPS2R2i		DPS1R2i		
T12		DPS2R1ii	DPS1R1i				Processing
T13			DPS2R1i	DPS1R1i	DPS2R2i		
T14			DPS1R2ii	DPS2R1i		Processing	Processing
T15			DPS2R2ii		DPS1R2ii	Processing	
T16			DPS1R1ii		DPS2R2ii		Processing
T17			DPS2R1ii	DPS1R1ii			Processing
T18					DPS2R1ii	Processing	

4.3 Main Idea

From Figure 8 and Table 1, Node A is the busiest mobile host in this scenario. In ODMRP, each node transmits received message as soon as it finishes processing the message and senses that it is free to access the medium. In this case, the medium is the radio transmission channel. This is done at MAC layer. MAC stands for Medium Access Control. It is layer 2 of OSI 7-layer network architecture.

Every time a mobile host wants to send any data packets, it has to use one of several schemes for the MAC layer to obtain radio channel information. The Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) is one of the access schemes used in wireless LANs following the standard IEEE 802.11 [6]. It works as follows. A sender senses the medium to see if it is free. If the medium is free, the sender starts transmitting data and continues to listen to the medium. If the medium is busy, it pauses a random amount of time before sensing the medium again and repeating this cycle pattern.

Every time a mobile host does this, it creates overhead for the transmission process. Most mobile hosts are equipped with single transceiver. Transceiver is a small pocket radio with a built-in transmitter and receiver. It can transmit and receive signals from a single radio channel. It is not able to transmit or receive more than one message at one time. Refer to Table 1 again. DPS1R1ii is second data packet sent from S_1 to R_1 . After it reaches Node A at T_{10} , it has to wait for the radio channel to get cleared before it can be sent at

T16. When a user data packet is generated by a source node, it has information to reach the next hop node. Once it reaches a forwarding node, the information it carried will be replaced by the routing information that the forwarding node has. Messages from any nodes use the same information before the routing table is updated or refreshed. Thus, two messages from different nodes may carry the same routing information and the same destination address when they reach the same node before it changes its routing table.

To reduce overhead of ODMRP in this area, a scheme is proposed to combine any two or more data packets that have the same destination address. It will reduce the overhead of sensing medium. It will also reduce duplicated information from these combined packets.

Also, suppose that a mobile host wants to join the multicast group. It wants to become a member of a forwarding group as well. In ODMRP, nodes can leave a multicast group anytime and no explicit control message is required to do so. Suppose that node X decides to leave right after it becomes a forwarding node. By now, all nodes on the multicast group have updated their routing tables with node X as one of the forwarding nodes. Thus, Node X's leaving may cause data delivery failure. Senders have to retransmit the same data. Everyone else has to generate a new routing table if it has enough information. Otherwise, someone has to flood the network to get a new snapshot of the new topology.

Here, leaving without a control message can cause overheads; however, this does not mean it is better to do the other way. As authors of ODMRP stated

in their paper [11], the protocol uses no explicit control message to reduce channel/storage overhead. It may create extra traffic if an explicit control message is required to leave the group.

To solve this problem, a new algorithm is proposed here. A node can still leave the multicast group without explicit control message. When a node wants to join the multicast group, it has two options. The first option is that it has to guarantee a staying time if it wants to join the multicast group and become a member of a forwarding group. The second one is that if it does not want to commit a period of time to stay, it can become a member of the multicast group only.

Table 2 shows a simplified time table of what traffic is like with the new improvement. Several data packets have been combined. The radio channel is freed up a lot. The total number of cells in either table is 126. There are 86 free cells in the proposed scheme whereas 75 free cells in ODMRP. Free cells are increased from 59% to 68% by using the proposed scheme.

Table 2. A timing table for proposed scheme

	S1	S2	A	B	C	R1	R2
T1	JQS1	JQS2					
T2			JQS1				
T3			JQS2	JQS1	JQS1		
T4				JQS2	JQS2	JRR1S1	JRR2S1
T5				JRR1S1	JRR2S1	JRR1S2	JRR2S2
T6			JRR2S1	JRR1S2	JRR2S2		
T7	DPS1R1i		JRR2S2				
T8	DPS1R2i		JRR2S2				
T9	DPS1R2ii	DPS2R2i	JRR1S2				
T10	DPS1R1ii	DPS2R1i	DPS1R2i DPS2R2i				
T11		DPS2R2ii			DPS1R2i DPS2R2i		
T12		DPS2R1ii	DPS1R1i DPS2R1i				Processing
T13				DPS1R1i DPS2R1i			
T14			DPS1R2ii DPS2R2ii			Processing	
T15					DPS1R2ii DPS2R2ii		
T16			DPS1R1ii DPS2R1ii				Processing
T17				DPS1R1ii DPS2R1ii			
T18						Processing	

4.4 Proposed Protocol

All-To-All Multicast Routing Protocol (ATAMRP) will be presented in this section. Some source code is listed in the Appendix. The simulation program uses C language.

4.4.1 Multicast Routing Creation

Group membership and multicast routes are established and/or updated by the source on demand. There exist two phases: a request phase and a reply phase. When a multicast source has user data to send but no route or group information is available, it broadcasts a Join Query packet. When a node receives a Join Query packet, it stores the source address and the unique ID of the packet to detect duplicates. It will then rebroadcast the Join Query with its own address as per the previous hop address.

When the message reaches a multicast receiver, the receiver creates a Join Reply packet. The node will select a route based on the minimum delay, the route taken by the first Join Query received. The Join Reply packet contains the next hop address among others. It broadcasts the Join Reply packet. When a node receives the Join Reply message, it looks up the next hop address. If it does not match its own address, the node does nothing. If it matches its address, the node builds its own Join Reply and rebroadcasts it. It will insert the next hop address from its own routing table.

When a source node receives the Join Reply, it has two choices: commit a preset staying time and become a member of the forwarding group and multicast

group, or reject guaranteed staying time commitment and become a member of the multicast group only. Either way, the source node can transmit user data now with received routing information.

4.4.2 Data packets handling

When a node receives a data packet, it decides the type of data and calls the data handler of the type. It works as follows:

Begin

If ((None_duplicate) and (nodeAddr != destAddr))

 If (type == Join Reply)

 HandleJoinReply(message)

 If (type == JoinQuery)

 HandleJoinQuery(message)

 If (type == UserData)

 HandleUserData(message)

 Else

 Ignore

Else If ((None_duplicate) and (nodeAddr == destAddr))

 Process message

End

 Procedure HandleJoinReply(message).

Begin

If (None_Duplicate and nodeAddr != destAddr)

```
Update MessageCache
Update RouteTable
Retrieve NextNodeAddr(RouteTable)
Retransmit(message, NextNodeAddr)
If (None_Duplicate and nodeAddr = destAddr)
    Process Message
    If (commit StayingTime)
        Join Multicast Group
        Set Forwarding Group Flag
        Transmit UserData
    Else
        Join Multicast group
        Transmit UserData
Else
    Ignore
End

    Procedure HandleJoinQuery(message).
Begin
If (None_Duplicate)
    Update MessageCache
    Update RouteTable
    Hop_Count = Hop_Count + 1
```



```

If (node == multicast group member)
    Generate JoinReply
    Transmit JoinReply(nextHopNode(s))
End if

Broadcast JoinQuery

End

Procedure HandleUserData(message).

Begin

If (None_Duplicate and ForwardingGroupFlag)

    If (nodeAddr != destAddr)

        Delay(transmitting)

        If ((destAddr(currentMessage) == destAddr(incomingMessage))

            NewMessage = Combine (currentMessage, incomingMessage)

            Trim_Off (NewMessage, duplicated_info)

            Transmit(NewMessage)

        End if

        Transmit (UserDataPacket)

    End

End

```

The delay used in user data handling should be at least twice of the time of what is needed for the user data packet to travel between two neighboring nodes. Most user data packet sizes are 512 bytes which is 4096 bits. Assume that throughput of radio channel is 2,000,000 bits per second. It will take a user

data packet approximately 2 milliseconds to travel. It should be proficient to set the delay time to 5-7 milliseconds. This will also give enough time to process data packets.

CHAPTER 5

SIMULATION MODEL AND METHODOLOGY

5.1 Simulation Model

A simulation model for evaluating multicasting protocols has been developed within the GloMoSim library [2]. There exist a number of issues extremely challenging in high-level design for the digital communication, including the large scale, mix of voice, data, and imagery. Dynamically changing of connectivity in unpredictable ways and very high quality of service are often required. The GloMoSim is a scalable simulation library for wireless network systems built using the PARSEC simulation environment.

PARSEC (PARAllel Simulation Environment for Complex system) is a C-based simulation language developed by the Parallel Computing Laboratory at UCLA. It is used for sequential and parallel execution of discrete-event simulation models [3].

Most network systems adopt a layered architecture. GloMoSim is being designed using a layered approach similar to the OSI seven-layer network architecture. There are simple APIs (Windows Application Programming Interface) defined between different simulation layers. This lets different developers work at different layers to develop integrated models rapidly. These simple APIs are predefined to support their composition. They specify parameter exchanges and services between neighboring layers. For example, the APIs

between MAC layer and Network layer have two data packet specifications: one is from MAC to Network, and the other is from Network to MAC. Data packet from MAC to Network will have three fields: *payload*, *packetSize*, and *sourceID*. The *SourceID* refers to the previous hop from which the packet arrived. Data packet from Network to MAC also has three fields but they are slightly different. It consists *payload*, *packetSize* and *destID*. The *destID* refers to the next hop where the packet will travel. Several other simple APIs are also specified in the documentation.

With this layered design, actual operational code can be very easily integrated into GloMoSim. It is ideal for a simulation model as those actual operational codes have been validated in real life. For example, a TCP model has been implemented in GloMoSim by extracting actual code from the FreeBSD operating system. This significantly reduced the amount of coding required to develop the model.

Table 3 lists the GloMoSim models currently available at each of the major layers. New models are being added to the GloMoSim library. It also supports two different node mobility models. One is generally referred to as the "random waypoint" model [4]. A node chooses a random destination within the simulated area and moves to that location with the speed specified in the configuration file. After reaching its destination, the node pauses for a duration that is also specified in the configuration file. The other is referred to as the "random drunken" model. Here, if a node is currently at position (x,y) , it can possibly move

to $(x-1,y)$, $(x+1,y)$, $(x,y-1)$, or $(x,y+1)$ as long as the new position is within the simulated area.

Table 3: Models Currently in the GloMoSim library

Layer:	Models:
Physical (Radio propagation)	Free Space, Rayleigh, Ricean, SIRCIM
Data Link (MAC)	CSMA, MACA, MACAW, FAMA, 802.11, FAMA, TSMA
Network (Routing)	Flooding, Bellman-Ford, OSPF, DSR, WRP, FishEye, NS_DSDV, Static, AODV
Transport	TCP, UDP
Application	Telnet, FTP, HTTP

5.2 Simulation Methodology

The simulation models a network of 50 mobile hosts which are placed randomly within a 1000m by 1000m area. The channel capacity was 2 Mbits/sec. Each simulation executed for 600 seconds of simulation time. Different seed numbers were used to conduct multiple runs for each scenario and data was collected and averaged over those runs.

A free space propagation model for physical layer was used in the experiments. The IEEE 802.11 MAC was used as the MAC protocol. A traffic generator was developed and implemented in GloMoSim to simulate constant bit rate sources. For the new scheme, all-to-all multicast routing protocol, the number of senders is set to be equal to the number of receivers. All of these parameters above can be set in configuration file of the GloMoSim library.

5.3 Simulation Result

Each node moved constantly with the predefined speed. The moving directions of each node were randomly selected. When nodes reached the simulation terrain boundary, they returned back and continued to move. The node movement speed was varied from 10 km/hr to 72 km/hr.

Figure 9 illustrates the number of control packets per data packet delivery to destinations. ATAMRP, the proposed routing protocol, uses an algorithm to combine two data packets that have the same destination address. A user data packet will wait for a certain amount of time to see if there is another packet of the same type coming in within this time frame. If there is one, both packets'

headers will be removed, packets will be combined and a single new header will be attached to the new combined packet. Fewer data packet transmissions are needed because of the combining. Fewer control packets (Join-Query, Join-Reply, etc.) are transmitted. One additional advantage here is that the radio channel is freed up. This allows other nodes to access the radio channel if needed.

Figure 10 shows the total user data packets transmitted by all nodes. This is the count of every individual transmission of data by each node over the entire network. This count includes transmissions of packets that are eventually dropped and retransmitted by forwarding group nodes. The ATAMRP has lower transmission counts. Lower data packet transmission means a lower chance of requiring Join-Query transmission in case no valid routing information is available.

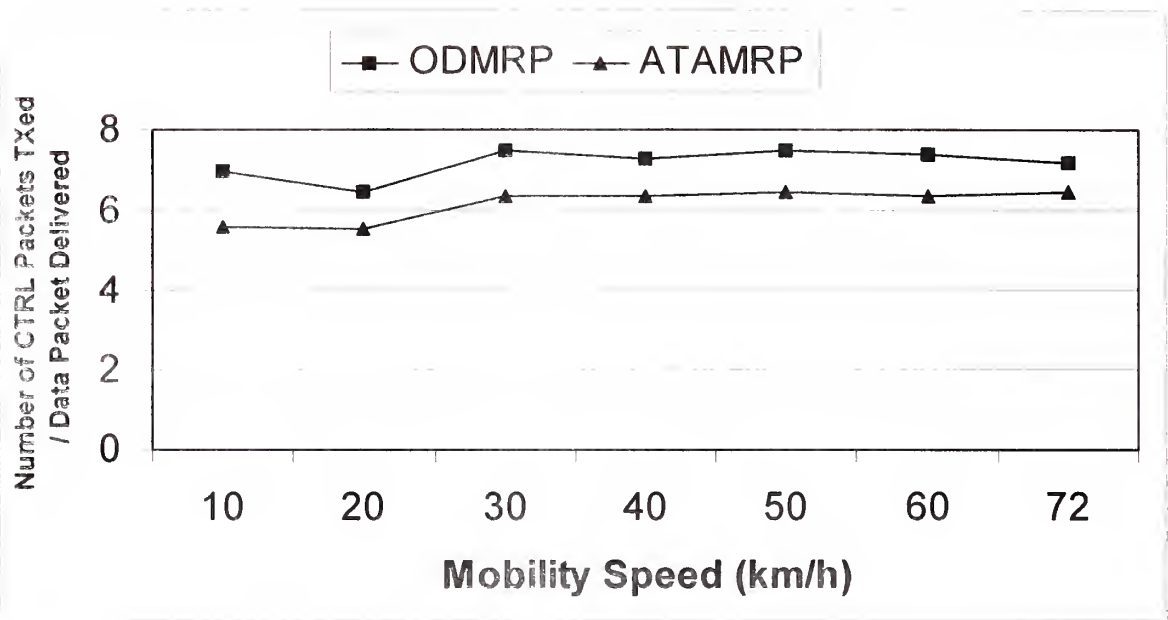


Figure 9. Number of CTRL packets transmitted per data packet delivered as a function of mobility speed

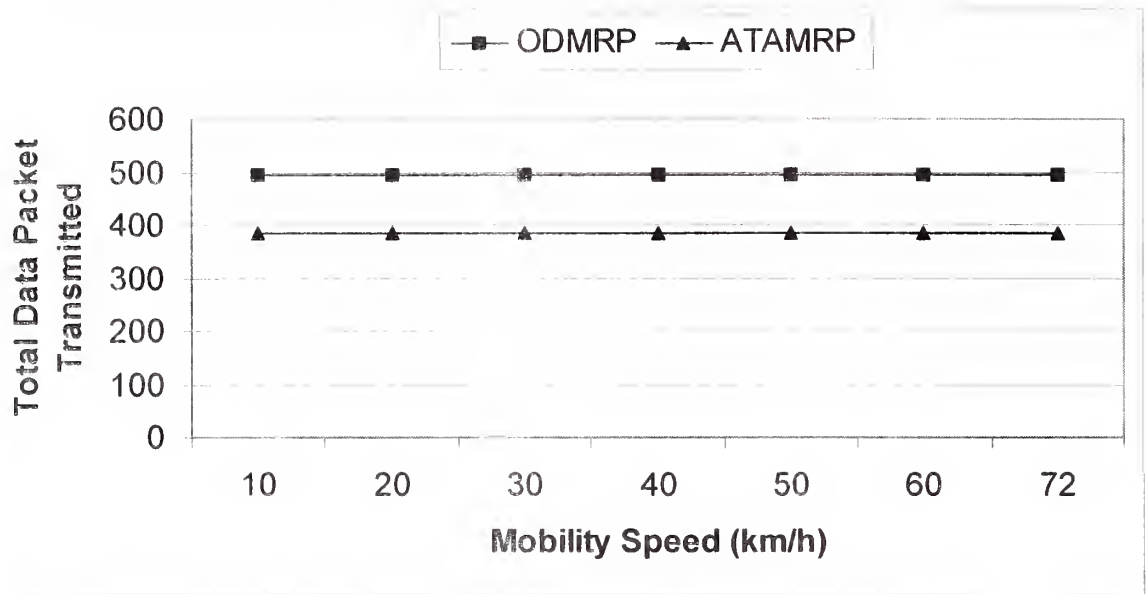


Figure 10. Total data packets transmitted

CHAPTER 6

CONCLUSION

This thesis proposes a scheme for multicast routing protocol in a wireless ad-hoc network. In this scheme, a node will hold any packets it receives for an extra preset time. If another packet of the same data type with the same destination address arrives within the preset time, the two packets will be combined and duplicated information will be removed. Node requesting to join the group will have a chance to choose either to commit a staying time or just send what it needs to and leave. Timing tables show that the radio channel is freed up significantly in the proposed scheme. Computer simulation shows that the proposed scheme can reduce control overheads significantly. Fewer control packets are transmitted with the proposed scheme. ATAMRP is well suited for ad hoc wireless networks with mobile hosts where bandwidth is limited, topology changes frequently and rapidly, and power is constrained.

Perhaps the prototypical application requiring ATAMRP is mobile conferencing. When mobile computer users gather outside the normal office environment, the business network infrastructure is often missing. But the need for collaborative computing might be even more important here than in the everyday office environment.

Even though this thesis proposed a scheme to reduce the control overheads, more research should be done on more efficient channel utilization,

the network structure, and the membership control, etc. for the all-to-all multicast in a wireless ad hoc network. Further research is ongoing on the membership control.

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APPENDIX: LIST OF PUBLICATIONS

Z.H. Zhou and S.M. Yoo, "All-to-All Multicast Routing Protocol in Wireless Ad Hoc Networks," under preparation to submit to IEEE Wireless Communications and networking Conference, Orlando, March 2002.

S.M. Yoo and Z. H. Zhou, "All-to-All Communication in Wireless Ad Hoc Networks," ACM Southeast 39th Conference, Athens, Georgia, pp. 180-181, March 2001.

APPENDIX: SOURCE CODE

```

BOOL RoutingAtamrpCombineOrNot(Glomo_Node destAddr, clocktype
timestamp, Atamrp_MC *messageCache)
{
    Atamrp_MC_Node *current;

    if (messageCache->size == 0)
    {
        return (FALSE);
    }

    for (current = messageCache->front; current != NULL;
        current = current->next)
    {
        if (current->timestamp > (timestamp -
            Atamrp_COMBINE_TIMEOUT)
            && current->destAddr == destAddr)
        {
            return (TRUE);
        }
    }
    return (FALSE);
} /* RoutingAtamrpCombineOrNot */

if(RoutingAtamrpCombineOrNot(destAddr, timestamp, &Atamrp-
>messageCache))
{
    GLOMO_MsgFree(node, msg);
}
else
{
    option.lastAddr = node->nodeAddr;
    option.hopCount++;
    SetAtamrplpOptionField(msg, &option);
    delay = pc_erand(node->seed) * ATAMRP_BROADCAST_JITTER;

    NetworkIpSendPacketToMacLayerWithDelay(node, msg,
    DEFAULT_INTERFACE, ANY_DEST, delay);

    Atamrp->stats.numDataTxed++;
}

```