MULTICAST ROUTING PROTOCOL WITH PARTIAL FLOODING FOR AD HOC WIRELESS NETWORKS

BY

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A Thesis Presented to the

DEANSHIP OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

In

COMPUTER ENGINEERING

JUNE 2001

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This thesis, written by **ABDUL AZIZ YAGOUB BARNAWI** under the direction of his thesis advisor and approved by his thesis committee, has been presented to and accepted by the Dean of Graduate Studies, in partial fulfillment of the requirements for the degree of **MASTER OF SCIENCE IN COMPUTER ENGINEERING**

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Dedicated

to

My beloved family

Acknowledgments

All praise be to ALLAH, *The most beneficial the most merciful.* Best prayers and greetings to our holy prophet, peace be upon him and his family.

All praise be to ALLAH, the Great, for having mercy on me and giving me the courage, patience and determination to carry out this work. Acknowledgment is due to King Fahd University of Petroleum and Minerals for supporting this research.

I would like to express my deepest appreciation and gratitude to my thesis advisor, Dr. Habib Youssef, for his patient guidance and continuous support. Dr. Youssef has been helpful and provided me with support to achieve this goal. I also thank my thesis co-advisor, Dr. Abdulaziz S. Almulhem, who guided me throughout my thesis and research, for his comments and critiques. Thanks to my thesis committee member Dr. Sadiq M. Sait for his generous academic and moral support during my thesis and course work in KFUPM. Thanks are to my committee members Dr. Khalid Salah and Dr. Muhammad F. Khan, who have been very kind and provided me with advice and support.

Acknowledgements are also due to my parents and family members who always supported me in carrying out my academic career.

I thank all my colleagues in the department and the college who directly or indirectly supported and helped me in carrying out this work successfully.

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THESIS ABSTRACT

Name: ABDULAZIZ YAGOUB BARNAWI

Thesis Title: MULTICAST ROUTING PROTOCOL with PARTIAL FLOODING for AD HOC WIRELESS NETWORKS

Major Field: COMPUTER ENGINEERING

Date of Degree: JUNE 2001

Ad hoc networks are dynamically reconfigurable wireless networks with no fixed infrastructure or central administration. Applications such as disaster recovery, crowd control, etc., are practical applications for these networks. Such applications are group oriented in nature with high QoS demands, which means an efficient multicast routing protocol is very important. Multicast routing protocols for wired networks are not suitable in this environment, since ad hoc networks consist of severely limited bandwidth links and low power hand held devices. In this work we are proposing a new approach for multicast routing in mobile ad hoc networks. The scheme follows the on-demand forwarding group approach, and occasionally utilizes limited flooding. It utilizes global control messages sent by the source node to refresh the multicast group members and route information, as well as local beacon messages sent by all forwarding nodes to determine the current mobility state of their downstream nodes. These beacon messages are used by forwarding nodes to detect when downstream nodes move out of their transmission range, and therefore switch to scoped flooding.

MASTER OF SCIENCE DEGREE

King Fahd University of Petroleum and Minerals, Dhahran.

JUNE 2001

ملخص الرسالة

الأسم: عبد العزيز يعقوب برناوي

موضوع الرسالة: بروتوكول متعدد الإرسال مع إستخدام جزئي للإرسال الفيضاني في الشبكات اللاسلكية العشوائية

التخصص: هندسة الحاسب الآلي

تاريخ التخرج: يونيو ٢٠٠١

الشبكات اللاسلكية العشوائية (Ad Hoc Networks) هي شبكات ديناميكية الهيكلة و بدون بنية تحتية محددة أو ادارة مركزية، ومن التطبيقات العملية لهذه الشبكات معالجة الكوارث، التحكم بالزحام، إلخ وتتميز هذه التطبيقات بأنها جماعية، كما أنها تحتاج إلى جودة عالية في الخدمة وبالتالي فإنه من المهم جداً إستخدام بروتوكول متعدد الإرسال(MulticastProtocol) ذو كفاءة عالية. ألبروتوكولات متعددة الإرسال المستخدمة في الشبكات السلكية تعتبر غير ملائمة للشبكات اللاسلكية العشوائية لأن هذه الشبكات تتكون من خطوط إتصال ذات سعة نطاق محدودة، كما أن الأجهزة المستخدمة فيها هي أجهزة محمولة ذات سعات تخزين محدودة. هذا البحث يطرح طريقة جديدة لبروتوكول متعدد الإرسال للشبكات اللاسلكية العشوائية. البروتوكول المطروح يستخدم طريقة مجموعة الإتصال التوجيهي عند الطلب. بالإضافة إلى ذلك فإنه أحياناً يَستخدم طريقة الإرسال الفيضاني المحدود (Scoped Flooding). رسائل التحكم الصادرة عن المرسِل تُستخدم لتحديث المجموعة الموصلة و طرق الإرسال، كما أن جميع أعضاء المجموعة الموصِلة يستخدمون رسائل محلية لمعرفة الحالة الحركية لأعضاء المجموعة الواقعين في طريق الإرسال. هذه الرسائل المحلية تُستخدم لمعرفة خروج عضو المجموعة القريب من مدى الإستقبال وبالتالي فإن أعضاء المجموعة تتحول لإستخدام الإرسال الفيضاني المحدد.

رسالة الماجستير في العلوم

جامعة ألملك فهد للبترول والمعادن، ألظهران

يونيو ٢٠٠١

Chapter 1

Introduction

1.1 General

Mobile Ad Hoc Networks (MANETs) are networks where all nodes are mobile. In an Ad Hoc Network (AHN) (MANET and AHN refer to the same throughout this document) there is no distinction between a host and a router since all network hosts can be endpoints as well as forwarders of traffic. The popularity of such networks is increasing due to the fast development of the mobile hand-held and portable devices. MANETs work to create "a peer-to-peer mobile routing capability in a pure mobile wireless domain". Short-term goals are to develop intra-domain unicast routing protocols and network layer technology. Mobile routing capability is based on IP to provide network layer consistency. This is because physical layer can utilize any kind of wireless solution. Long-term goals include unicast routing issues as well as advanced mobility services, multicasting, and QoS extensions [1]. Due to the limited radio propagation range of wireless devices, routes are often multihop, that's why an AHN is called Multi-hop AHN as shown in Figure 1.1.

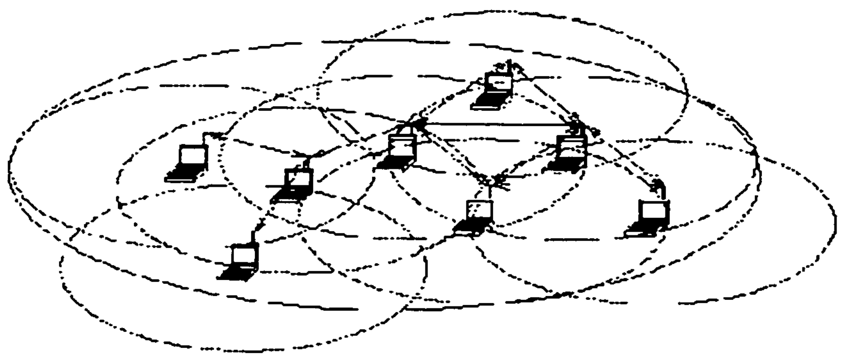


Figure 1.1: An Ad Hoc Wireless Network.

Nodes in these networks move arbitrarily, thus network topology changes frequently and unpredictably. A topology change is illustrated in Figure 1.2. In addition, bandwidth and battery power are limited. These constraints, in combination with the dynamic network topology make routing in ad hoc networks extremely challenging.

Applications such as disaster recovery, crowd control, search and rescue, and automated battlefield management are typical examples of where AHNs are deployed. Some of these applications involve video and audio conferencing for remote meetings as well as one-to-many data dissemination. Multicasting is the fundamental enabling technology for such group communication applications.

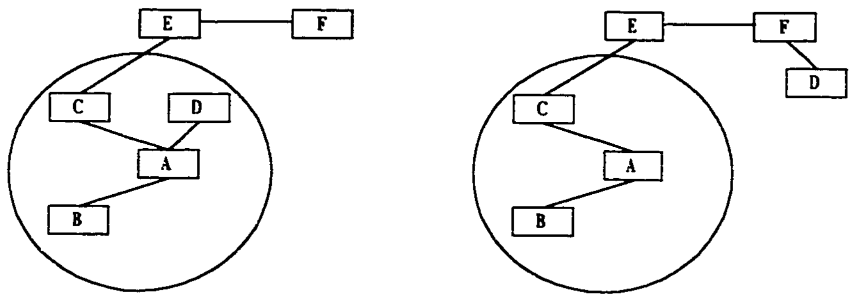


Figure 1.2: Topology Change Example.

Unconstrained mobility implies the following:

1. Individual host behavior is independent of other hosts.

2. Essentially no limit on host speed.

3. No constraints on direction of movement.

4. High probability of frequent, temporary network partitions.

The previously mentioned stringent constraints on MANETs show that routing protocols for wired networks are not suitable for MANETs. That is because those protocols are mostly based on periodic exchange of link and topology information either globally or locally. This approach, if applied on AHNs, will severely affect their robustness and efficiency.

Specifically, multicast routing and packet forwarding protocols in AHNs must emphasize the following [2]:

1. **Robustness vs. Efficiency:** A well designed multicast protocol must adapt to the dynamic changes of the network without overloading it with control traffic.

2. **Active Adaptability:** AHN has a dynamic behavior and there is no multicast protocol that can be considered efficient for all circumstances. Mobile hosts may dynamically switch among different multicast mechanisms based on their mobility behavior. This must be done with little overhead on nodes and network resources.

3. **Unlimited Mobility:** Some existing multicast solutions have restricted assumptions about nodes movement patterns and network size. However, a more realistic assumption is a *universal* mobility of *all* network components in a large scale.

4. **Integrated Multicast:** Future demands on AHN requires the availability of seamless and integrated multicast service. New mechanisms must be developed for inter-operation of fixed and wireless multicast.

1.2 Proposed Work

In this work we present a new approach for multicast routing in mobile ad hoc networks. The scheme follows the on-demand *forwarding group* approach, and occasionally utilizes limited flooding. It utilizes global control messages sent by the source node to refresh the multicast group members and route information, as well as local beacon messages sent by all forwarding nodes to determine the current mobility state of their downstream nodes. These beacon messages are used by forwarding nodes to detect when downstream nodes move out of their transmission range, and therefore switch to flooding.

1.3 Thesis Organization

The rest of this document is organized as follows: Chapter 2 reviews the published literature that addresses routing and multicasting issues in ad hoc wireless networks. Chapter 3 reviews ODMRP in details as an important part in our work. In Chapter 4 we discuss our proposed work and motivation for it. Chapter 5 addresses the issue of protocol performance analysis of our scheme, and details of the simulation environment, tools used, and results obtained. Finally, we conclude in Chapter 6 by comments and future work.

Chapter 2

Literature Review

This chapter reviews the proposed algorithms for unicast and multicast routing in MANETs. It talks about protocols classification, pros and cons of each scheme, and other related issues.

2.1 Unicast Routing in MANETs

Many routing protocols have been proposed in the literature, some of them are better than others depending on assumptions made about network size and applications. Those protocols can be classified either as *proactive*, *reactive*, or *hybrid* based on how route discovery and maintenance are performed. Proactive protocols attempt to continuously determine the network connectivity so that the route is already available when a packet need to be forwarded. Dynamic Destination-

Sequenced Distant-Vector protocol (DSDV) [3], the Wireless Routing Protocol [4], Global State Routing protocol [5], Fisheye State Routing protocol [6], Hierarchical State Routing protocol [6], Zone-based Hierarchical Link State Routing [7], and Clusterhead Gateway Switch Routing protocol [8] fall in this category. Reactive protocols, in contrast, invoke a route discovery procedure only on demand, i.e., when a packet needs to be sent. In such a case, some sort of global search is performed. Cluster based Routing protocol [9], Ad Hoc On-Demand Distance Vector protocol (AODV) [10], Dynamic Source Routing protocol (DSR) [11], Temporally Ordered Routing protocol (TORA) [12], Associativity Based Routing protocol [13, 14], and Signal Stability Routing protocol [15] are types of Reactive Routing Protocols.

Proactive schemes posses little delay when a route is acquired, however, reactive schemes may have significant delays specially when the route to destination is not available. Moreover, the global search procedure of the reactive schemes may produce significant control traffic, which is undesirable in this limited bandwidth environment. Despite that, purely proactive protocols are also not desirable, as they continuously use a large portion of the network capacity to keep the routing information current. Since nodes move quite fast in an AHN, and as changes may be more frequent than the route requests, most of this routing information is never even used. This results in a further waste of the network capacity. In addition, they require large storage capacity at mobile nodes. This may violate the robustness feature of the protocol if the network size gets very large and the storage capacity of mobile nodes is limited.

In hybrid schemes, like the Zone Routing Protocol (ZRP) [16, 17], proactive operations are performed within a specific zone. A sender will exchange state information with receivers that in its zone, while it is reactively searching for destination nodes outside its zone. The zone size is specified with the maximum hops that state information can traverse.

2.2 Multicast Routing in MANETs

Multicast routing for MANETs has been investigated by many researchers during the last couple of years. The changing behavior of ad hoc networks requires a careful treatment of establishing and maintaining the multicast group membership. Some techniques require no control overhead like flooding at the expense of creating many duplicate packets traversing the network at the same time. Some techniques consume a lot of bandwidth by sending many control packets (*proactive*), while others are smarter in their way of achieving the same task (*reactive*). Examples of proactive ones are the Ad Hoc Multicast Routing Protocol (AMRoute) [18], Ad hoc Multicast Routing protocol utilizing Increasing id-numberS (AMRIS) [19], Core-Assisted Mesh protocol (CAMP) [20], Multicast Core-Extraction Distributed Ad hoc Routing (MCEDAR) [21], and Forward Group Multicast Protocol (FGMP) [22], On the other hand, Multicast Ad Hoc On Demand Distance Vector (MAODV) protocol [23], and

On-Demand Multicast Routing Protocol (ODMRP) [24] are examples of the reactive scheme.

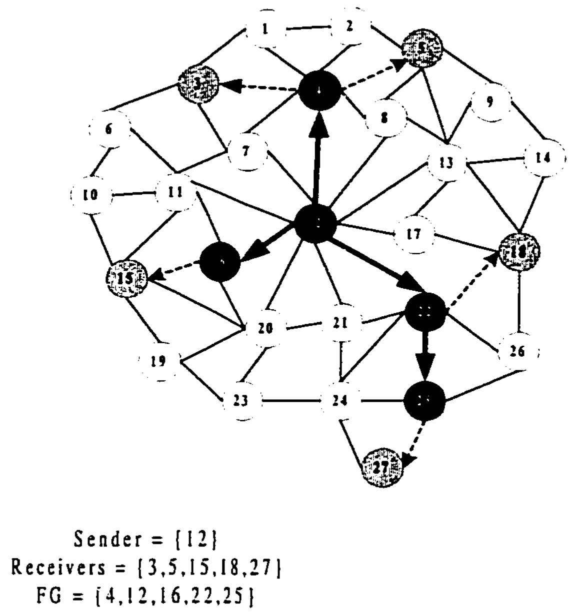
Another classification of ad hoc multicast protocols is based on the built structure, i.e., multicast *mesh* or multicast *tree*. Examples of tree based protocols are the Shared Tree Wireless Network Multicast protocol [25], the Adaptive Shared Tree Multicast protocol [26], the On-Demand Shared Tree protocol with Hybrid State [27], FGMP, AMRIS, MAODV, and AMRoute. While Neighbor Supporting Ad hoc Multicast Routing Protocol (NSMP) [28], ODMRP, CAMP, and MCEDAR are examples of mesh based multicast protocols.

In addition to that, some multicast techniques are designed taking energy consumption or bandwidth as important route quality measures. A multicast protocol based on bandwidth availability has been proposed by *Bhattaharya et al.* [29]. In that, a shared tree is created, where routes are built only if sufficient bandwidth exists along every link of the route. Each node on the network should be able to execute the algorithm independently to decide which connection requests to accept, where to forward the requests if required to do so and which frequencies to allocate. For this, the node will need to gather information from surrounding nodes and evaluate a cost function(s) to manage the tradeoff between routing efficiency and network congestion. Several algorithms are proposed in [30], where they consider the power of transceivers as a metric to evaluate a certain route. The ways in which wireless network characteristics, as well as the constraints of limited energy, affect the multicast protocol operation is discussed in [31].

2.2.1 Multicast Membership Creation Techniques

There are two major techniques used for creating and maintaining a multicast group: *receiver advertisement* (RA) and *sender advertisement* (SA). In the RA, each receiver periodically and globally floods its member information in the form of Join-Request. When a sender receives this Join-Request from receiver members, it updates the Member Table. This table is used to hold an entry for each member and associate it with a timer. Expired receiver entries will be deleted from the member table. Figures 2.2 and 2.3 show the format of Join-Request packet and Member Table, respectively, used in (FGMP) [22]. The sender will broadcast multicast packets only if the member table is not empty. After updating the member table, the sender creates from it the Forwarding Table (FT) shown in Figure 2.4. This table is broadcast by the sender to all neighbors. Only neighbors listed in the next hop list accept this forwarding table. Each next hop node creates its forwarding table by extracting the entries where it is the next hop neighbor and again using the preexisting routing table to find the next hop, etc. This process continues until all receivers are reached.

In contrast, in the sender advertisement (SA) technique the sender will flood its information periodically to the whole network. In such case the receivers will periodically broadcast Join Tables instead of FTs. Join tables have the same format as FTs except that the Join Tables contain the senders IDs in place of receivers IDs.



Forwarding Table of Node 12:

Receiver	Next hop
3	4
5	4
15	16
18	22
27	22

Forwarding Table of Node 22:

Receiver	Next hop
27	25

Figure 2.1: Example of Forwarding Tables used in FGMP.

Mcast Group ID	ID	Sequence num	TTL

Figure 2.2: Format of Join Request Packet.

Mcast Group ID	
Refresh Timer	
Receiver Member ID	Timer

Figure 2.3: Format of member table at the sender.

Mcast Group ID	
Receiver Member ID	Next Hop
:	

Figure 2.4: Format of Forwarding Table (FT).

The performance of those schemes is formulated in [32] as follows, in FGMP-RA each node broadcasts its information once; therefore the total number of receiver advertisement transmissions, Ara, is given by

$$Ara = N \cdot R \cdot \frac{Tsim}{Tra} \tag{2.1}$$

where $Tsim$ is the total simulation time; Tra is the interval of receiver advertisement flooding; N is the number of nodes in the network; and R is the number of receivers. In addition to that, a forwarding table is forwarded along the shortest path to receivers and the nodes along the shortest path are chosen as forwarding nodes. The number of forwarding table transmissions is equal to the number of forwarding nodes. Therefore, the total number of forwarding table transmissions, $FTra$, is given by

$$FTra = \sum_{j} FGj \tag{2.2}$$

Where FGj is the number of forwarding group nodes at the j^{th} transmission of Forwarding-Tables. From (2.1) and (2.2), the total communication overhead of FGMP-RA, Cra, is given by

$$Cra = Ara + FTra = N \cdot R \cdot \frac{Tsim}{Tra} + \sum_j FGj \tag{2.3}$$

The communication overhead of FGMP-SA is estimated in the same way [32]. The total number of sender advertisement transmissions, Asa, is given by

$$Ara = N \cdot \frac{Tsim}{Tsa} \tag{2.4}$$

where Tsa is the interval of sender advertisement generation. The total number of joining table transmission $JTsa$ is given by

$$JTsa = \sum_j \sum_k H_{ki} \tag{2.5}$$

where H_{ki} is the hop count from the receiver k to the sender at the i^{th} transmission of Join-Tables. From (2.4) and (2.5), the total communication overhead of FGMP-SA, Csa, is given by

$$Csa = Ara + JTsa = N \cdot \frac{Tsim}{Tsa} + \sum_j \sum_k H_{ki} \tag{2.6}$$

It is clear from Equations 2.3 and 2.6 that the advertisement interval is a major factor that increases the communication overhead in both cases. If the network is very dynamic, many link failures will happen which will require a small refresh interval, which means increasing overhead. It is clear also that FGMP-SA will have a lower overhead than FGMP-RA especially if the number of senders is much less than the number of receivers which is the case in most the practical situations.

Simulation of both schemes shows that, the *sender advertisement* scheme has a better multicast efficiency and throughput than *receiver advertisment* [22]. It also shows that the control overhead increases as mobility increases. All results satisfy the previously formulated equations.

The previously discussed techniques are based on what is called *Soft State* scheme since there is no explicit join or leave messages from receivers, only using timers. However, some protocols are based on *Hard State* scheme. *Tomochika et al.* proposed such scheme [32], in which a receiver floods a JOIN packet until it reaches a forwarding node or a receiver node of the desired multicast group (see Figure 2.5). REPLY packets are replied back to the receiver through the reverse path. Upon receiving this REPLY, the receiver will send a RESERVE packet along the path the REPLY packet has traversed. When a receiver node wants to leave the multicast group, it sends a QUIT packet to its upstream node. Upon receiving the QUIT packet, the upstream node checks if it has any downstream node that is a receiver. If it has any other downstream node it simply deletes the receiver from the downstream entry in the multicast routing table. Otherwise, it sends a QUIT packet to its upstream node and leaves the multicast group.

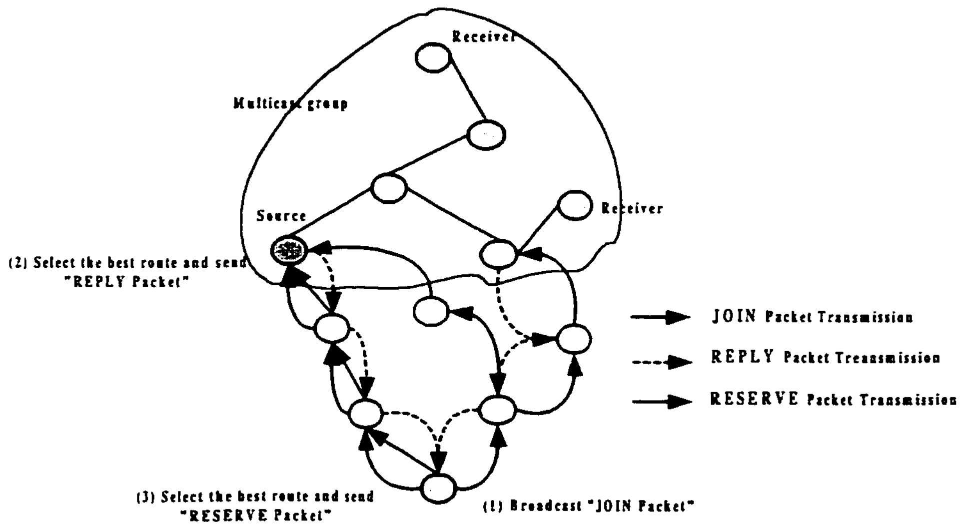


Figure 2.5: Hard State Scheme.

2.2.2 Proactive Multicast Protocols

As mentioned before, proactive protocols continuously exchange control information to keep the state of the network upto date. A systematic algorithm is followed to build tree or mesh and maintain it.

AMRoute is a tree based proactive protocol. It creates a bidirectional shared tree using unicast tunnels to provide connections between multicast group members. Each group has at least one logical core that is responsible for member and tree maintenance. Initially, each group member declares itself as a core for its own group of size one. Each core periodically floods JOIN-REQ to discover other disjoint mesh segment for the group. When a member node receives a JOIN-REQ from a core of the same group but a different mesh segment, it replies with a JOIN-ACK and marks that node as a mesh neighbor. The node that receives a JOIN-ACK also marks the sender as its mesh neighbor. After the mesh creation, each core periodically transmits TREE-CREATE packets to mesh neighbors in order to build a shared tree. When a member node receives a non-duplicate TREE-CREATE from one of its mesh links, it forwards the packet to all other mesh links. If a duplicate TREE-CREATE is received, a TREE-CREATE-NAK marks the link as mesh link instead of tree link. The nodes wishing to leave the group send the JOIN-NAK to the neighbors and do not forward any data packets for the group.

After mesh creation, non-member nodes do not forward data packets and need not support any multicast protocol. AMRoute relies on an any underlying unicast protocol to maintain connectivity among member nodes.

CAMP [20] supports multicasting by creating a shared mesh structure. All nodes in the network maintain a set of tables with membership and routing information. More over, all member nodes maintain a set of caches that contain previously seen data packet information and unacknowledged membership requests. CAMP classifies nodes in the network as duplex or simplex members, or non-members. Duplex members are full members of the multicast mesh, while simplex members are used to create one-way connections between sender-only nodes and the rest of the multicast mesh. "Cores" are used to limit the flow of JOIN REQUEST packets.

Mesh creation in CAMP is done through the use of JOIN REQUEST or CAMP UPDATE packets. A node wishing to join a multicast mesh first consults a table to determine wither it has neighbors which are already members of the mesh. If so, the node announces its membership via a CAMP UPDATE. Otherwise, the node either propagates a JOIN REQUEST towards one of the multicast group "Cores" or attempts to reach a member router by an expanding search of broadcast requests. Any duplex member of the node can respond with a JOIN-ACK, which is propagated back to the source of the request.

2.2.3 Reactive Multicast Protocols

Reactive or (on-demand) multicast techniques create group membership and multicast routes only on-demand, i.e., whenever the source has data to send.

One of the early proposed reactive multicast protocols is an extension of the AODV, called Multicast Ad Hoc On-Demand Distance Vector (MAODV). Its basic operation consists of two main phases: route discovery and tree maintenance. In the route discovery phase, a node wants to find a route to the multicast group will initiate a Route Request packet (RREQ). The destination address in this packet is set to the address of the multicast group. Nodes that want to be routers of the multicast group will set a flag called (J_Flag) in the RREQ packet. Only such nodes in the multicast tree may respond to a RREQ. After a RREQ is received, the node check if it is a group member or a tree member. If so, the node generate a Route Reply packet (RREP) and send it back to the requesting node. The new member will accept only the first received RREP. It will then generate a Multicast Route

Activation message (MACT), and send it to the node from which it received the first RREP. MACT will be discussed in detail in the maintenance phase. This process continues until a tree member is reached. This route from the new receiver upto the tree or group member will be the new route added to the multicast tree. Figure 2.6 shows an example of how the protocol works.

Fresh routes in MAODV are maintained by using Group Hello messages, which are sent globally by what's called *group leader*. Each new generated Hello is associated with a new sequence number to ensure fresh information about the group. A new Hello is transmitted if RREP is not received within a specific time interval. The nodes receiving the Group Hello will use it to update their request tables. If a node does have an entry for the advertised multicast group, one is inserted. This will be used to generate RREQ for new joining members.

The second phase of MAODV is to maintain the multicast tree. This phase has three different scenarios: activating a link when a new node joins the group, pruning the tree when a node leaves the group, and repairing a broken link. Route activation is done by using the MACT message, which has already been mentioned before. This message carries the source address. When a group member receives a MACT message, it enables the entry for the source node in its own multicast routing table. If a node is not a group member receives a MACT, it will forward it to the best next hop towards the multicast group. This node can select the best hop by extracting the hop count that is part of the RREP packet. MACT is also used for pruning the multicast tree if a node wants to leave the group. This is done by setting a flag in MACT, called the P_Flag, allowing the upstream node of the leaving node to remove the source entry from its routing table. The upstream node can do the same if it becomes a leaf and it is not a member.

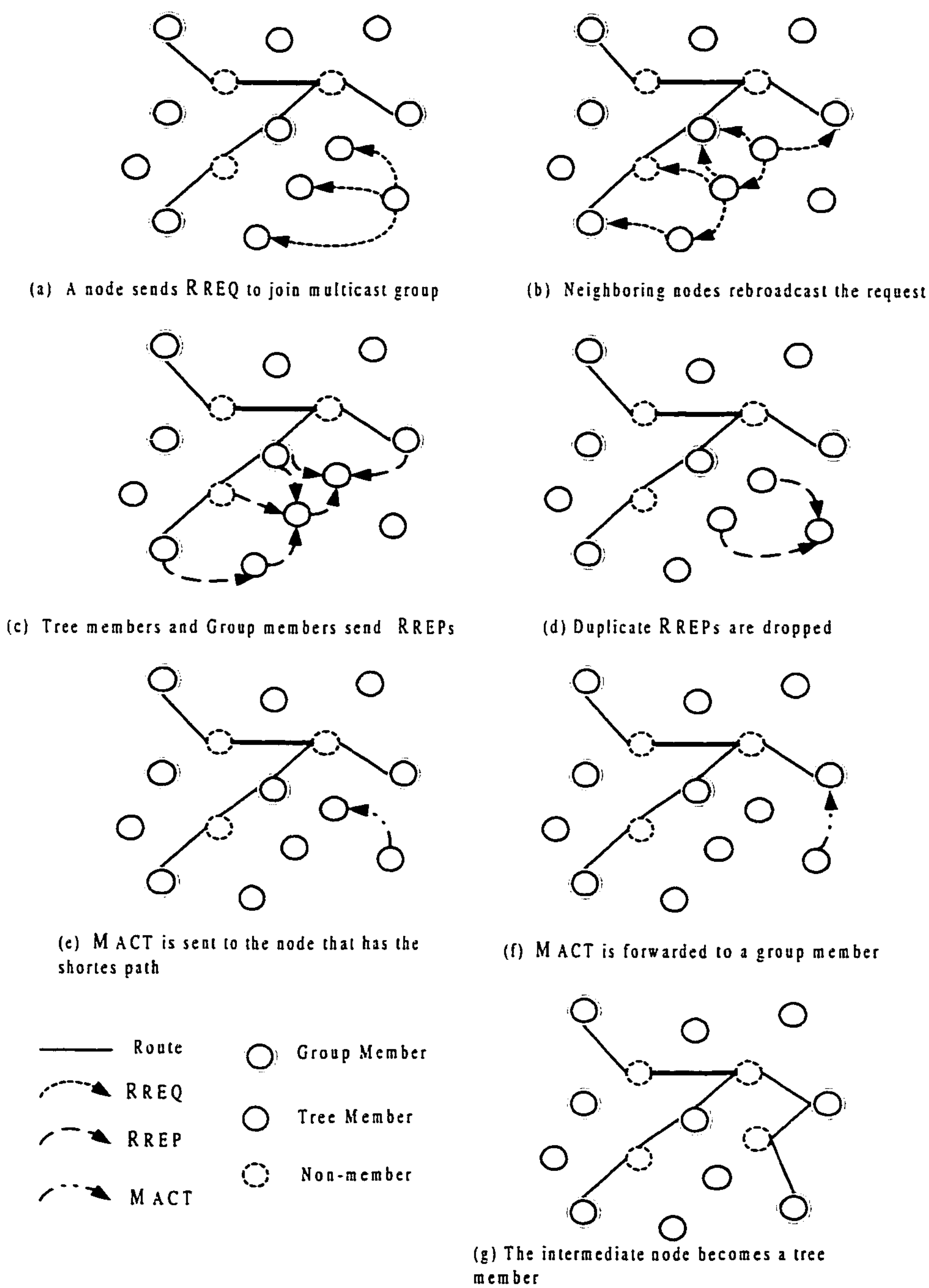


Figure 2.6: Multicast AODV tree branch addition.

Chapter 3

On-Demand Multicast Routing Protocol

ODMRP is considered as one of the most efficient mesh based multicast routing protocols for ad hoc wireless networks [33]. It falls into the category of on-demand protocols since group membership and multicast routes are established and updated by the source whenever it has data to send. In contrast to $tree - based$ multicast protocols, ODMRP builds a multicast mesh, where a subset of nodes, or *forwarding group*, are responsible for forwarding packets via scoped flooding. Using a mesh instead of a tree avoids many drawbacks of multicast trees in mobile networks (e.g., frequent tree reconfiguration, non-shortest path in a shared tree, traffic concentration, etc). It also minimizes overhead by using the $soft\ state$ scheme discussed in Chapter 2.

3.1 Multicast Route and Mesh Creation

Similar to other on-demand protocols, ODMRP consists of a request phase and a reply phase. While a multicast source has packets to send, it periodically broadcasts to the entire network a member advertising packet, called JOIN REQUEST (Figure 3.3, according to [34]), which is used to refresh the membership and update routes. When a node receives a non-duplicate JOIN REQUEST, it stores the upstream node ID and rebroadcasts the packet. When the JOIN REQUEST packet reaches a multicast receiver, the receiver creates or updates the source entry in its *Member Table*. While valid entries exist in the *Member Table*, JOIN TABLEs (Figure 3.4, according to [34]) are broadcast periodically to the neighbors. When a node receives a JOIN TABLE, it checks if the next node ID of one of the entries matches its own ID. If it does, the node is on the path to the source and thus is part of the forwarding group. It then sets a flag called the Fg_Flag and broadcasts its own JOIN TABLE. The JOIN TABLE is propagated by each forwarding group member until it reaches the multicast source via the shortest path. This continuous process constructs (or updates) the routes from sources to receivers and builds a forwarding group mesh, see Figure 3.1 [24].

The mesh topology provides richer connectivity among multicast members compared to trees. Flooding redundancy among forwarding group nodes helps overcome node displacements and channel fading. Figure 3.2 shows a mesh topology of a mul-

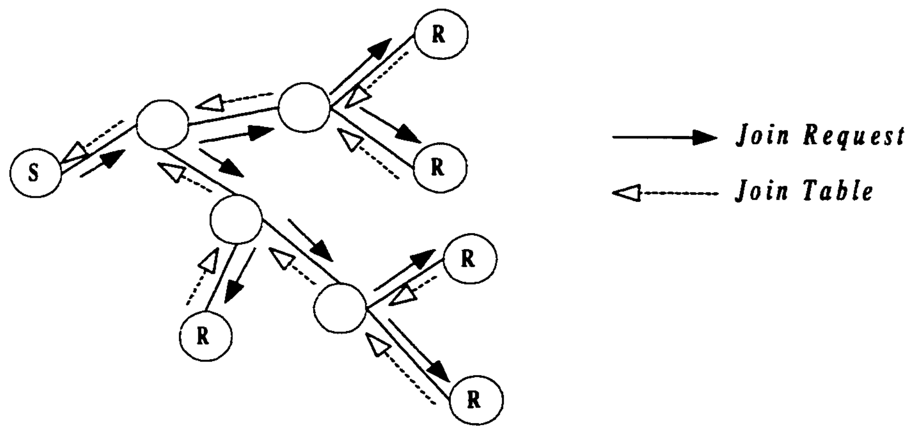


Figure 3.1: On-Demand Procedure for Membership Setup and Maintenance in ODMRP.

ticast group and the robustness of such configuration. For example, three sources (S_1, S_2, S_3) send multicast data packets to three receivers (R_1, R_2, R_3) via three forwarding group nodes (A, B, C). Suppose that the route from S_1 to R_3 is S_1-A-C-R_3. If the link (A-C) breaks or fails there is still a redundant route (e.g., S_1-A-B-C-R_3) to deliver packets without going through the broken link between nodes A and C [24].

After the group establishment and route construction process, a multicast source can transmit packets to receivers via selected routes and forwarding group nodes. Periodic control packets are sent only when outgoing data packets are still present. When receiving a multicast data packet, a node forwards it only if it is not a duplicate and the FG_Flag for the multicast group has not expired. Figure 3.5 is a flow chart representation for the protocol and Figure 3.6 shows events that happen due to expiration of timers like JOIN TABLE retransmission timer, multicast group timer, routing table timer, etc.

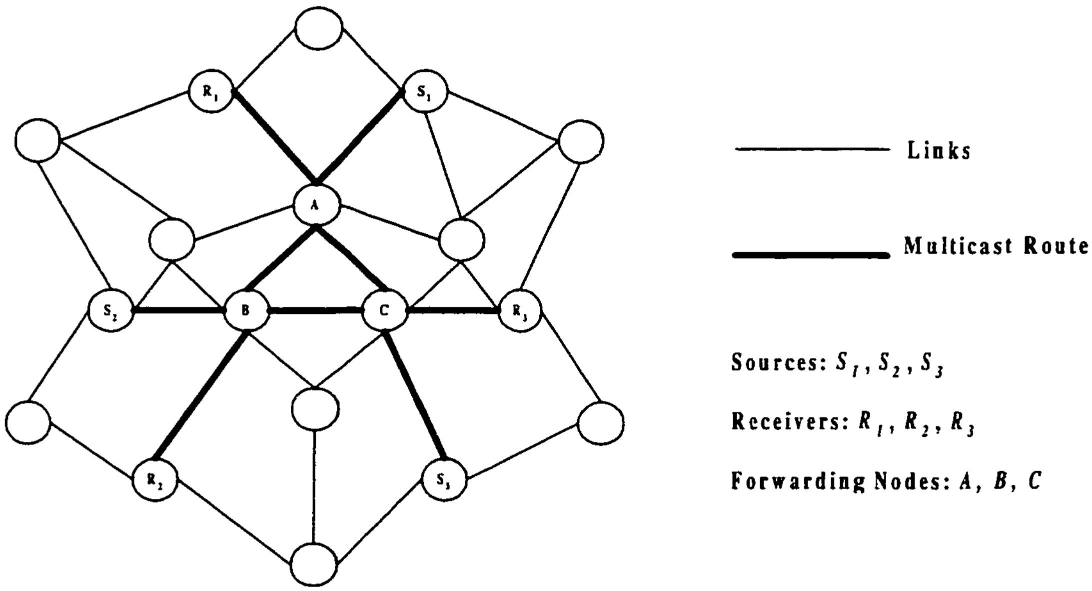


Figure 3.2: Robustness of Mesh Topology.

Type	Reserved	Time To Live	Hop Count
Multicast Group IP Address			
Sequence Number			
Source Hop IP Address			
Previous Hop IP Address			

Figure 3.3: ODMRP: Format of Join Request Packet Header.

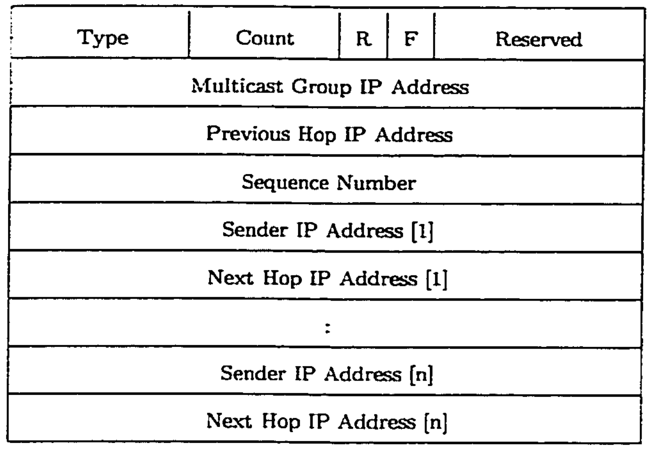


Figure 3.4: ODMRP: Format of Join Reply.

Field	**Size (bits)**	**Interpretation**
Type = 01	8	ODMRP Join Query
Reserved	8	Sent as 0; ignored on reception
Time To Live	8	Number of hops this packet can traverse
Hop Count	8	The number of hops traveled so far by this packet
Multicast Group IP Address	16	The IP address of the multicast group
Sequence Number	16	The sequence number assigned by the source to uniquely identify the packet
Source IP Address	16	The IP Address of the node originating the packet
Previous Hop IP Address	16	The IP address of the last node that has processed this packet

Table 3.1: ODMRP Join Request Packet Header Fields.

Field	Size (bits)	Interpretation
Type = 02	8	ODMRP Join Reply
Count	8	Number of (Sender IP Address, Next Hop) Combinations
R	1	Acknowledgement request flag This flag is set when active acknowledgement packet is required
F	1	Forwarding group flag. It is set when the packet is transmitted by a forwarding group node
Reserved	14	Sent as 0; ignored on reception
Multicast Group IP Address	16	The IP Address of the multicast group
Previous Hop IP Address	16	The IP address of the last node that has processed this packet
Sequence Number	16	The sequence number assigned by the source to uniquely identify the packet
Sender IP Address [1..n]	16	The IP Address of the source of the multicast group
Next Hop IP Address [1..n]	16	The IP Address of the next node that this packet is target to

Table 3.2: ODMRP Join Reply Packet Fields.

3.2 Reliability

The reliable transmission of Join Tables is very important in establishing and refreshing multicast routes and forwarding groups. Failure in delivering Join Tables will affect the efficiency of ODMRP. Verification of successful transmission must be performed by the protocol. Even though, the IEEE 802.11 MAC protocol can perform reliable transmission by retransmitting the packet if no acknowledgement is received, at some times there might be more than a single upstream node and broadcasting the acknowledgement packet will disable the functionality of the IEEE 802.11 to detect failure of packet delivery [34].

Another option for reliable delivery is to subdivide the Join Reply into separate sub-tables, one for each distinct next node. These Join Replies are separately unicasted using a reliable MAC protocol such as IEEE 802.11 or MACAW [34].

3.3 Preventing Route Acquisition Latency

On-demand protocols suffer from the problem of having large delays in acquiring routes. This happens when the source performs a global search process using JOIN REQUEST to establish routes over which data goes through. ODMRP prevents that by flooding JOIN REQUEST with data payload attached, which produces what is called JOIN DATA. In this way, flooding of JOIN DATA will achieve data delivery, constructing and updating routes as well as eliminating route acquisition latency [35].

3.4 Mobility Prediction

An improvement to the main protocol is the use of mobility prediction technique by *Lee et al.* [34, 35], in which the sender utilizes some information provided by receivers regarding speed, direction, radio propagation range, etc., to estimate the time before a new JOIN REQUEST is flooded (this time is less than the minimum route expiration period). With this method the overhead of sender advertisement is reduced and the packet delivery ratio is increased. However, this scheme requires the ability of nodes to determine those parameters through special devices or by using the Global Positioning System (GPS).

3.5 Contents of Tables

Nodes running ODMRP are required to maintain the following tables:

3.5.1 Routing Table

A *Routing Table* is created on demand and is maintained by each node. An entry is inserted or updated when a non-duplicate JOIN REQUEST is received. The node stores the destination (multicast group source) and the next hop to the destination. This routing table provides the next hop information when transmitting JOIN REQUESTs.

3.5.2 Forwarding Table

All forwarding group nodes maintain the group information in the *Forwarding Table*. The multicast group ID and the time when the node was last refreshed are recorded.

3.5.3 Member Table

Each multicast receiver stores the source information in the *Member Table*. For each multicast group the node is a member of, the source ID and the time when the last JOIN REQUEST was received from the source is recorded. If no JOIN REQUEST is received from the source within a refresh interval, that entry will be removed.

3.5.4 Message Cache

A *Cache* is maintained by each node to detect duplicates. Source address and sequence number combinations are stored for each data or JOIN REQUEST packet received. Entries are removed from the cache after some time interval using LRU (Least Recently Used) or FIFO (First In First Out) schemes.

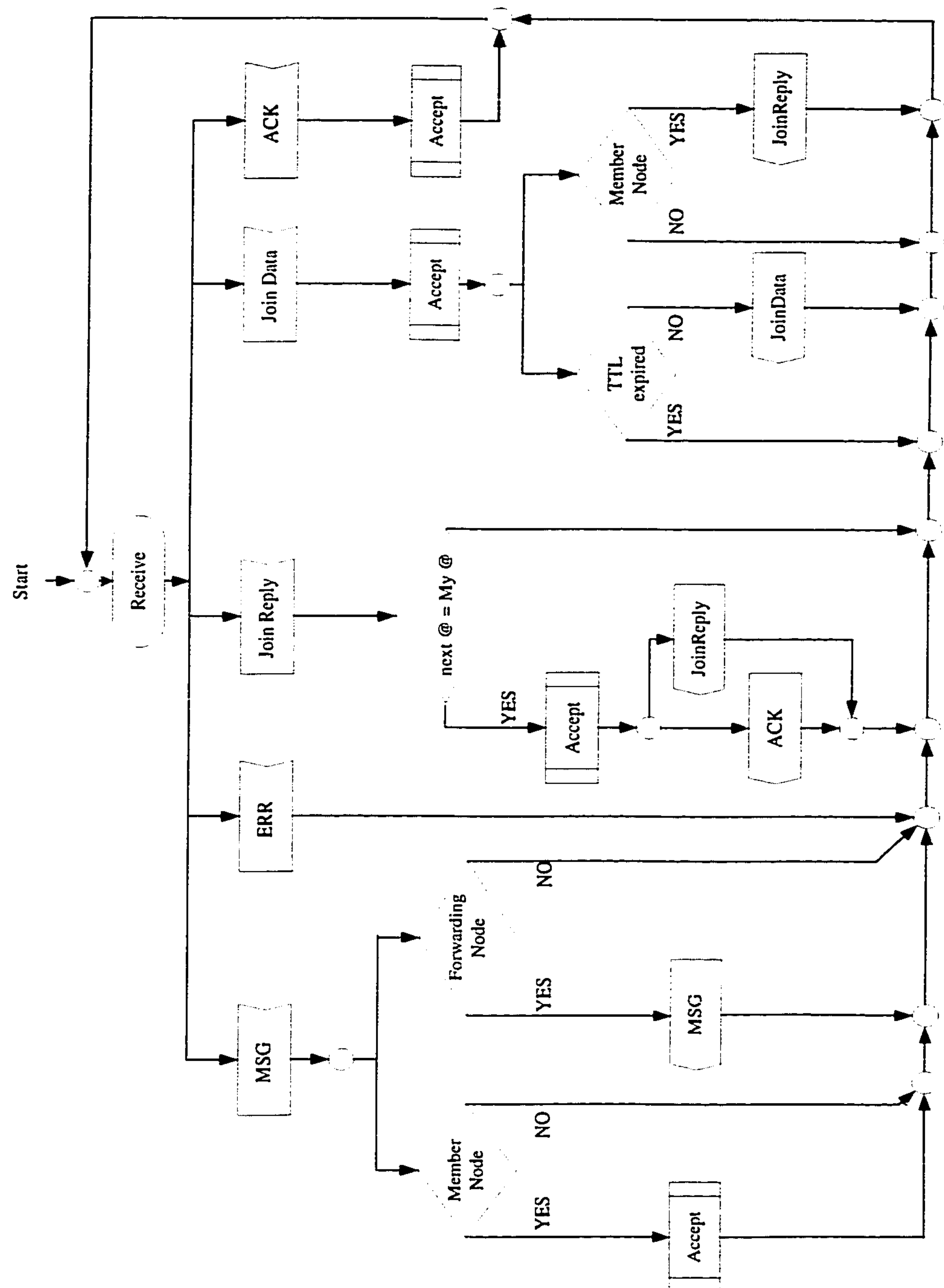


Figure 3.5: Flow chart representation for ODMRP.

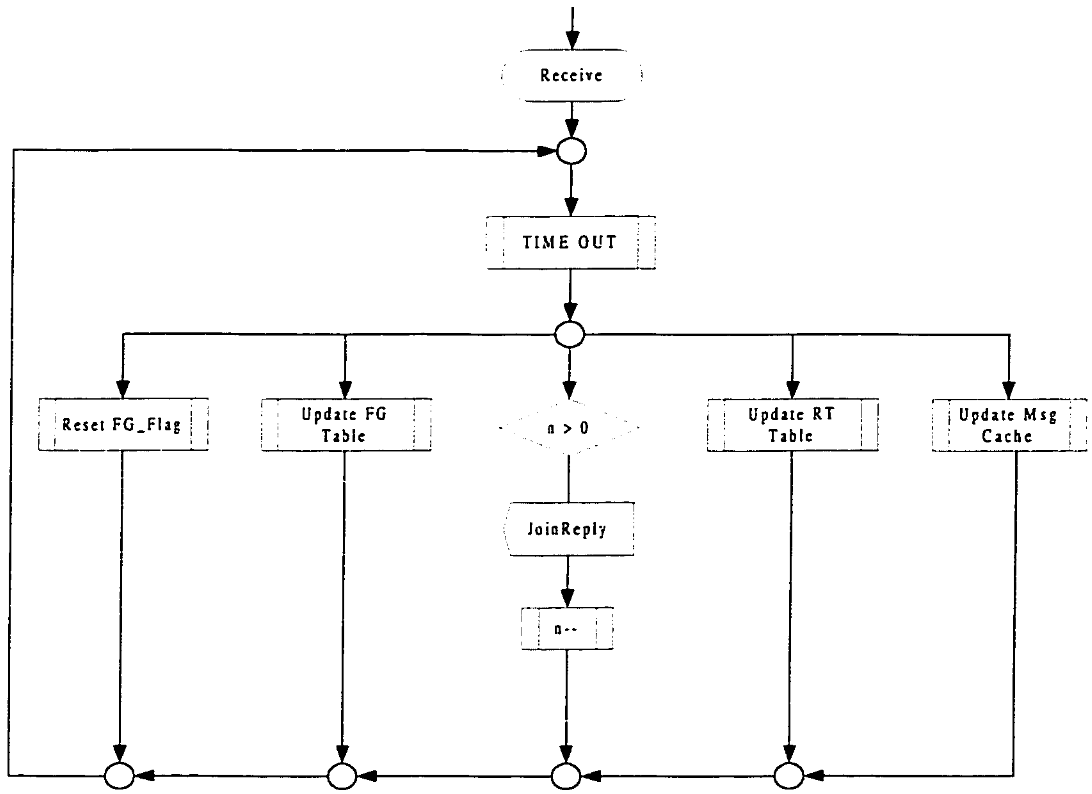


Figure 3.6: Timing Operations in ODMRP.

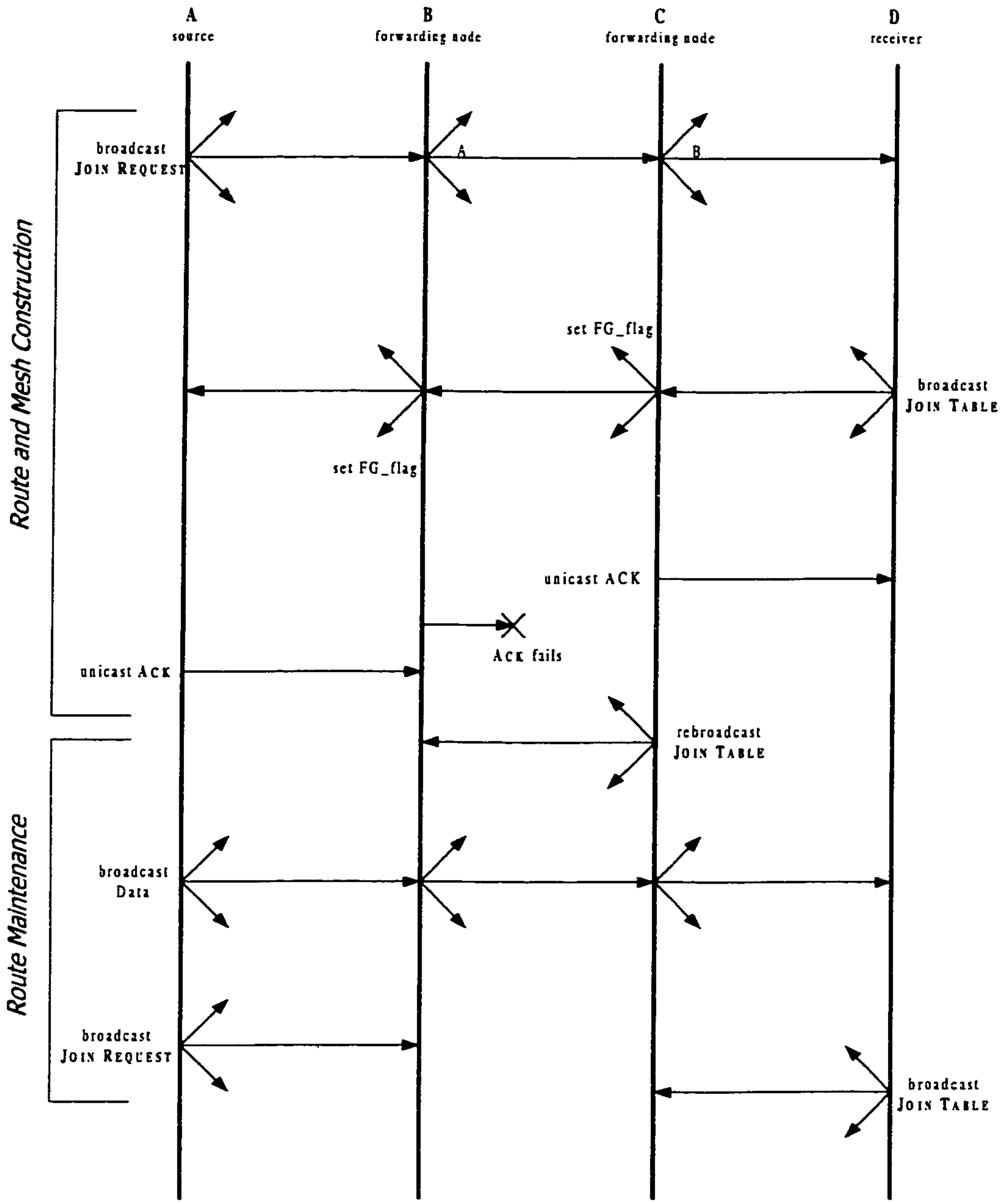


Figure 3.7: Basic operation of the ODMRP showing the building of the multicast routes. It reflects the behaviour of the source (A), receiver (D), and forwarding nodes (B,C) while forwarding JOIN REQUESTand JOIN TABLE packets. Data is sent only after the route construction.

Chapter 4

Partial Flooding

This chapter discusses our proposed scheme, motivation and basic concepts.

4.1 Motivation

Chapter 2 discussed all aspects of multicast protocols, pros and cons of each scheme and their suitability for specific scenarios and situations. Chapter 3 discussed ODMRP in details and how it can achieve high performance in terms of packet delivery ratio and control overhead. Mobility prediction also is shown to be effective in enhancing ODMRP efficiency at all mobility speeds. However, different studies over all protocols have shown that not all protocols perform well at all scenarios. Pure flooding discussed in [33] performs better than ODMRP and MAODV at different scenarios, especially if the number of senders is very small compared to the total number of nodes in the network. Also at high traffic rates (beyond 40 pkt/sec) ODMRP does not perform well. Furthermore, having a small number of receivers, will create a very poor mesh structure and, at high mobility speeds, nodes may move out of transmission range of the whole mesh and will not be able to receive packets. Another observation that we have noticed is that forwarding group nodes that are one hop away from the senders tend to move out of transmission range also, which will disconnect the senders from the mesh.

Despite that, pure flooding is not the best solution if the number of receivers is small compared to the network size, since that will lead to a very large number of redundant packets [36]. These redundant transmissions will produce a poor multicast efficiency. Hence pure flooding should be avoided if the number of receivers is small.

Frequency of exchanging control packets is very important for multicast protocols. Most of the time these control packets are sent globally. Whenever such a packet is received it will be retransmitted unless it is a duplicate. As stated previously, MANETs are based on limited bandwidth and contention based channels. Therefore, increasing the frequency of updates will lead to more collisions and packet loss. In addition, energy consumption should be of concern: all nearby nodes spend energy to process a broadcast packet, this is usually not true for a unicast packet.

In this research we are proposing an adaptive multicasting that uses global as well as local control packets to enhance the performance of multicast routing protocol.

4.2 Basic Concept

Implementation of our Partial Flooding protocol is basically built over the ODMRP. However, it can be built over any multicast routing protocol that uses the concept of the *forwarding group*. In this scheme we are emphasizing on the reduction of control overhead, but at the same time seeking to achieve high performance in terms of multicast efficiency and packet delivery ratio.

The protocol works in two phases: mesh creation phase and maintenance phase. It uses four control packets:

1. JOIN REQUEST
2. JOIN REPLY
3. ACK
4. HELLO

Operation of the algorithm works as follows: While a multicast source has packets to send, it periodically broadcasts to the entire network a member advertising packet, called JOIN REQUEST (Figure 3.3, according to [34]), which is used to refresh the membership and update routes. When a node receives a non-duplicate JOIN REQUEST, it stores the upstream node ID and rebroadcasts the packet. When the JOIN REQUEST packet reaches a multicast receiver, the receiver creates or updates the source entry in its *Member Table*. While valid entries exist in the

Member Table, JOIN TABLEs (Figure 3.4, according to [34]) are broadcast periodically to the neighbors. When a node receives a JOIN TABLE , it checks if the next node ID of one of the entries matches its own ID. If it does, the node is on the path to the source and thus is part of the forwarding group. It then sets a flag called the Fg_Flag and broadcasts its own JOIN TABLE. Before it does that, it records the source address of this JOIN TABLE in what is called *Down Stream Nodes Table*. The JOIN TABLE is propagated by each forwarding group member until it reaches the multicast source via the shortest path. This continuous process constructs (or updates) the routes from sources to receivers and builds a forwarding group mesh, see Figure 3.1.

At a predefined time after a *forwarding group* node broadcast its own JOIN TABLE, that node will start probing its downstream nodes by unicasting a HELLO packet to each one; see Figure 4.1. This hello message is used to know about the presence of a specific downstream node. The sender node will also perform the same process after it receive JOIN TABLE(s).

The IEEE 802.11 MAC layer protocol has the ability to detect failures of unicast packets delivery. Hence, any dropped HELLO packet will indicate that a downstream node has moved out of transmission range.

Downstream nodes might still be able to receive packets if they moved within the multicast mesh, however, it is highly likely that these nodes get disconnected from the multicast mesh and will not receive data. In such case it is found that there is no way for such nodes to receive multicast data except by flooding. Figure 4.2 shows a situation where Partial Flooding is introduced. The movement of node R_3 causes the link C - R_3 to fail. In that case forwarding node C will flood subsequent data packets with a hop count of 4. Any node that receives this packet will decrement its hop counter and rebroadcast it to its immediate neighbors only once. Eventually this packet will reach R_3. Forwarded packets with hop counter equals 0 will be discarded.

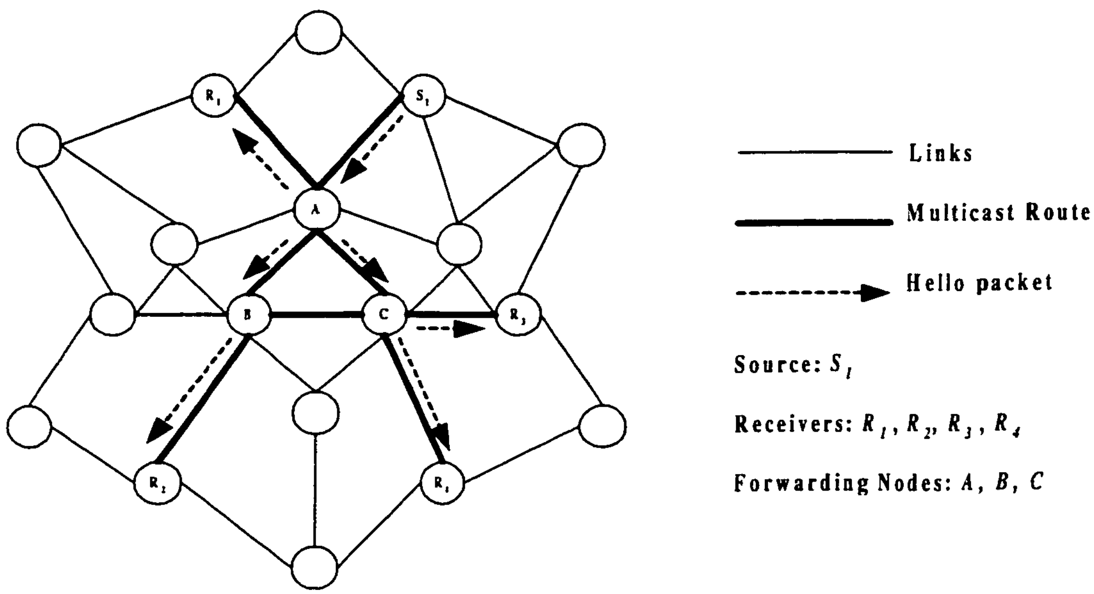


Figure 4.1: Hello Messages are unicasted to receivers and FG nodes.

HELLO packets are sent periodically as long as there is no dropped one. A single dropped HELLO packet will terminate sending extra packets until the next join refresh period. During the remaining time upto the next join refresh period, a node that has a previously dropped HELLO packet will flood future received packets to K number of hops by setting a counter on the packet's header. Any node in the network will rebroadcast that packet only if it is not a duplicate and the hop counter is greater than 0.

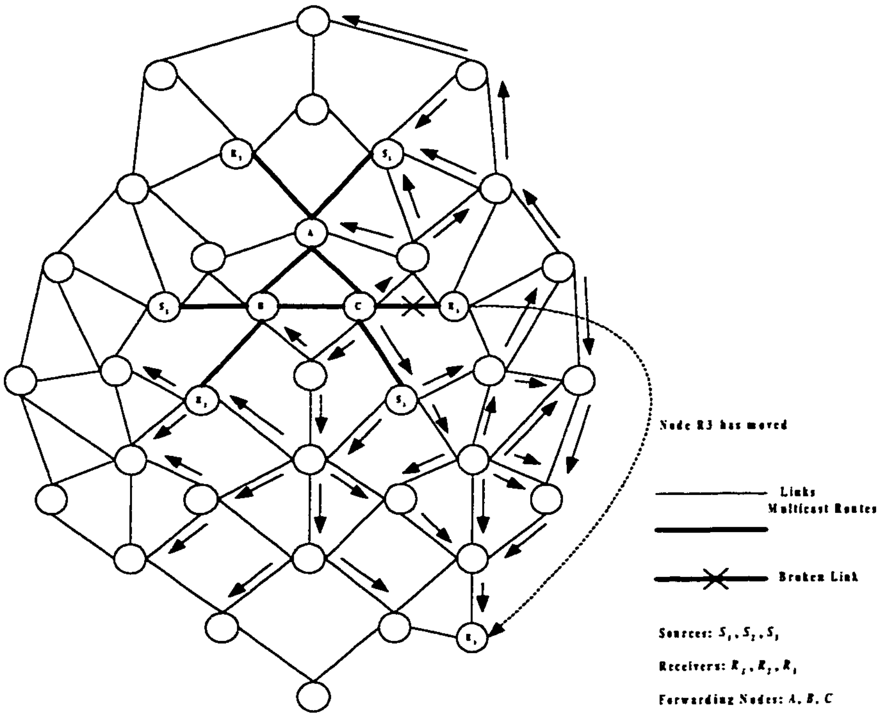


Figure 4.2: Partial Flooding due to the failure of link C - R_3.

Both Figures 4.3 and 4.4 explain the behavior of the protocol. Figure 4.3 is a flowchart describing the actions taken by the protocol after the reception of a certain packet, while Figure 4.4 is a time sequence diagram that explain the protocol according to the order of events happen during route construction and maintenance.

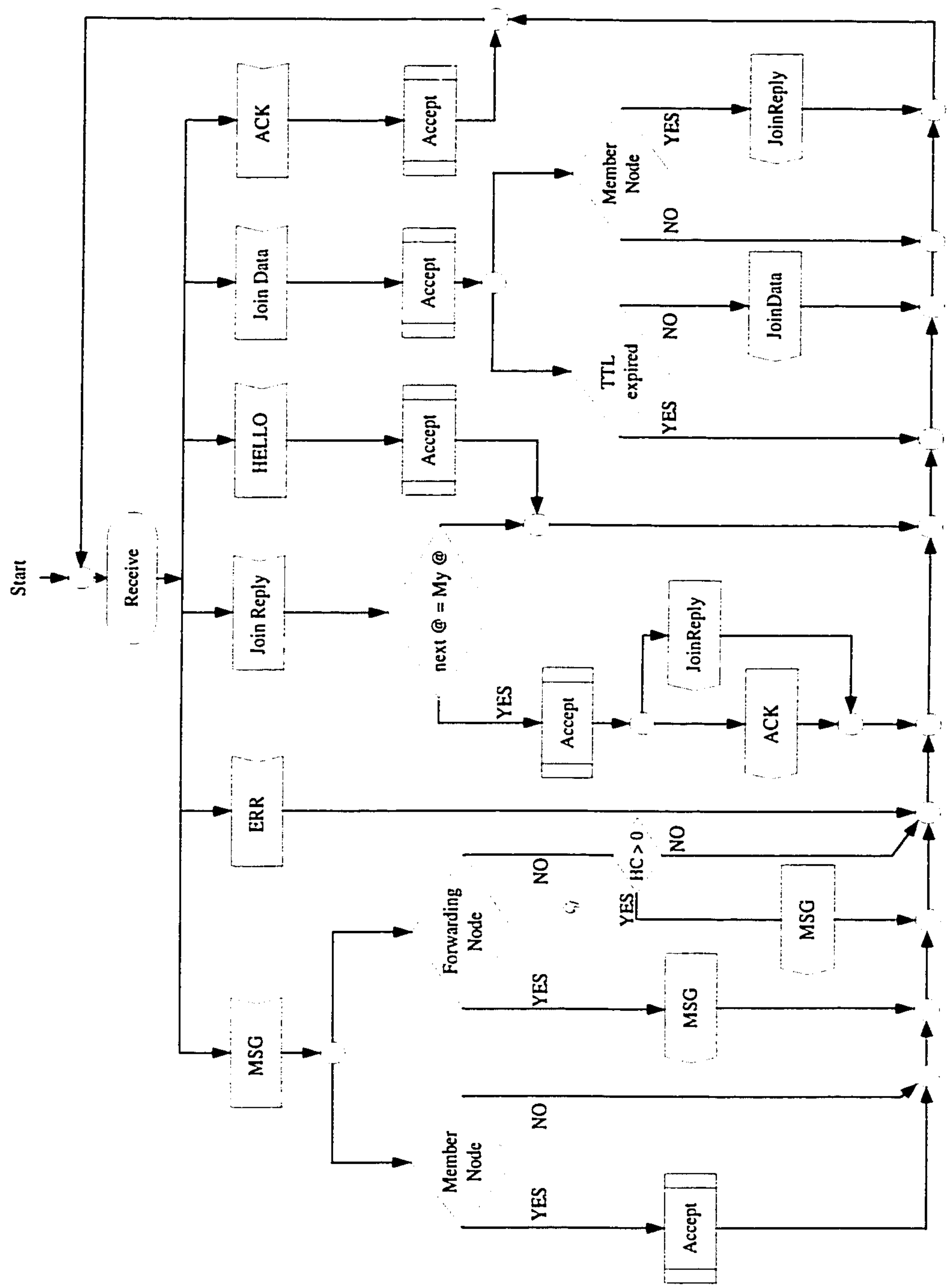


Figure 4.3: Flow chart representation for Partial Flooding over ODMRP.

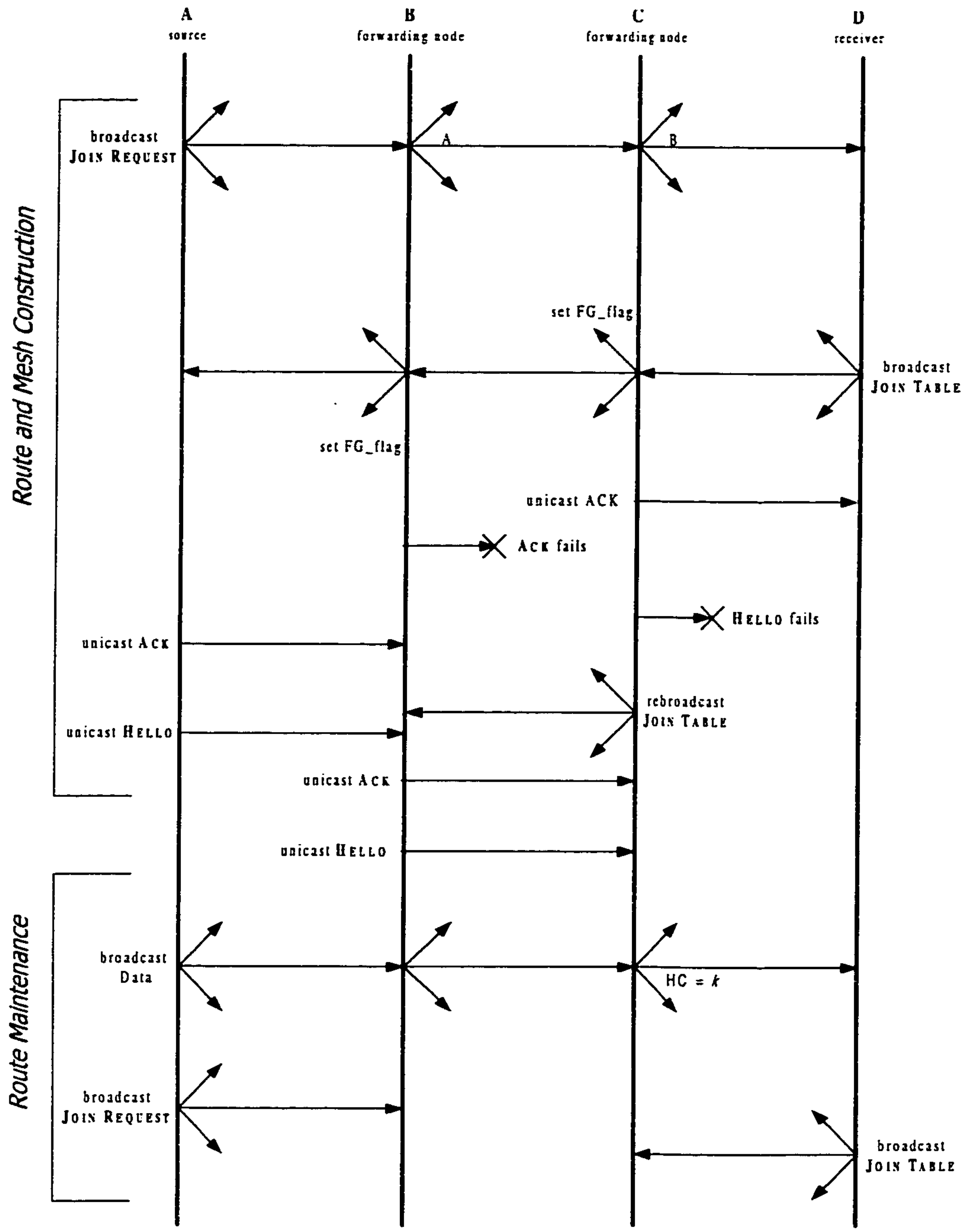


Figure 4.4: Basic operation of the Partial Flooding scheme showing the building of the multicast routes. It reflects the behaviour of the source (A), receiver (D), and forwarding nodes (B,C) while forwarding JOIN REQUEST and JOIN TABLE packets. Data is sent only after the route construction.

Chapter 5

Performance Analysis

This chapter discusses the performance analysis of the Partial Flooding scheme for multiple simulation scenarios.

5.1 Performance Metrics

Many performance measures have been considered in the literature and some of them were suggested by the IETF MANET working group for routing/multicasting protocol evaluation [1, 37]. The following measures are used in our simulation:

1. **Packet delivery ratio:** The ratio of the number of packets actually delivered to the destinations versus the number of data packets supposed to be received. This number represents the effectiveness of the protocol.

2. **Number of data packets transmitted per data packet delivered:** 'Data Packets transmitted' 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 intermediate nodes.

3. **Number of control bytes transmitted per data bytes delivered:** The ratio of control bytes transmitted to data bytes delivered. This value shows how efficiently control bytes are utilized in delivering data. One assumption made for this metric is that the data packet headers are also included in the control overhead.

4. **Number of control and data packets transmitted per data packet delivered:** This measure shows the efficiency in terms of channel access and is very important in ad hoc networks since link layer protocols are typically contention-based.

5.2 Simulation Environment

Simulation of wireless networks with different dimensions where the scale is large and network traffic is a mix of voice, data, and imagery is a challenging task. Connectivity over such networks is unpredictable and quality of service is severe. Special and a careful designed simulator is an important requirement to measure the performance of these networks.

GloMoSim (for Global Mobile Simulator) is a scalable simulation library for wireless network systems using the PARSEC simulation environment [38]. Both GloMoSim and PARSEC are designed by the UCLA Parallel Computing Lab [39]. GloMoSim is designed using a layered approach similar the one used in the TCP/IP protocol stack. Table 5.1 shows those layers and the current implemented protocols for each one. Standard APIs are used between the different simulation layers. The main feature of GloMoSim is that it provides detailed statistics for each layer, hence precise performance measures can be obtained.

LAYER	**MODELS**
Mobility	Random waypoint, Random drunken, Trace based
Radio Propagation	Free space, Two ray
Radio Model	Noise Accumlating
Packet Reception Models	SNR bounded, BER based with BPSK/QPSK modulation
Data Link	CSMA, MACA, and IEEE 802.11
Network(Routing)	Bellman-Ford, DSR, WRP, Fisheye, LAR scheme, AODV
Transport	TCP, UDP
Application	Telenet, HTTP, FTP, CBR

Table 5.1: GloMoSim Library Models.

In the following subsections some of the important simulation environment parameters will be briefly discussed.

5.2.1 MAC Layer (IEEE 802.11 with DCF)

The use of IEEE 802.11 in our simulation is very important because of its ability to detect failures of packet delivery at the MAC layer. This will enable nodes to take certain actions as needed. The fundamental mechanism to access the medium in the IEEE 802.11 is called Distributed Coordination Function (DCF). This is a random access scheme, based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol. Retransmission of the collided packets is managed according to binary exponential backoff rules.

DCF [40, 41] describes two techniques to handle packet transmission. The default scheme is a two-way handshaking technique called *basic access mechanism*. This mechanism is characterized by the immediate transmission of a positive acknowledgement (ACK) by the destination station, upon successful reception of a packet transmitted by the sender station. Transmission of the ACK must be explicit to enable the transmitter to determine successful reception.

The other scheme is based on a four way handshaking technique, known as Request-To-Send/Clear-To-Send (RTS/CTS) mechanism. In this technique, before transmitting a packet, a station operating in RTS/CTS mode "*reserves*" the channel by sending a special Request-To-Send short frame. The destination station acknowledges the receipt of an RTS frame by sending a Clear-To-Send short frame. After that, normal packet transmission and ACK response occurs.

5.2.2 Propagation Models

Land-mobile communication is affected with particular propagation complications compared to the channel characteristics in radio systems with fixed and carefully positioned antenna. The antenna height at a mobile terminal is usually very small. Hence, the antenna is expected to have a very little "clearance", which makes obstacles and reflection surfaces around the antenna to have a substantial influence on the characteristics of the propagation path. Three main propagation models are implemented in GloMoSim: Free Space, Rayleigh Fading Distribution, and Ricean Fading Distribution. Free space propagation model predicts received signal strength when the transmitter and receiver have a clear, unobstructed line-of-sight path between them. Received power decays as a function of the Tx-Rx separation distance, see Equation 5.1.

$$S_r = S_t\ G_t\ G_r\ (\frac{\lambda}{4\pi\ d})^2 \tag{5.1}$$

where S_r is Received Power in Watts; S_t is the Transmitted Power in Watts; G_t is the Transmitter Antenna Gain; G_r is the Receiver Antenna Gain; λ is the Wavelength; d is the Tx/Rx Separation Distance in same units as wavelength.

5.2.3 Wireless Transmission Range

A critical factor that highly affects packet loss in MANETs is the effective transmission range. This parameter is influenced by many structural issues surrounding MANETs, such as terrain shape, atmospheric conditions, and man-made obstacles. Another issue that determines the reception range is the transmission power: The larger the transmitted power, the longer is the reception range. However, large transmission power can significantly increase the power drainage and reduce the battery lifetime. Another important issue is the antenna configuration; i.e., not only the transmitter power is important, but how this power is spatially distributed is important as well [42].

Studies conducted in [43] showed that the best transmission range, which causes the minimum packet loss, is between 150 and 250 meters. That is reasoned by the fact that at low power ranges, packet loss is large due to node disconnectivity. While at higher power ranges, losses are mostly due to collisions. Although longer transmission range reduces the number of hops that a packet needs to traverse in an ad-hoc network, it also increases the number of nodes that locally compete on the shared channel, effectively reducing the network capacity [42].

In our simulation, like most proposed, we adopt the 250 meters transmission range choice. That is achieved by adjusting the transmission power of the transmitter to 7.87398 dBm.

5.2.4 Mobility Model

The mobility model that will be used is the *random waypoint* model. In this model, a node randomly selects a destination from the physical terrain. It then moves in the direction of the destination in a speed uniformly chosen between MOBILITY-WP-MIN-SPEED and MOBILITY-WP-MAX-SPEED. After it reaches its destination, the node stays there for MOBILITY-WP-PAUSE time period. This process is repeated during the whole simulation time.

5.2.5 Traffic Model

CBR simulates a constant bit rate generator according to the following format:

CBR $< src >$ $< dest >$ $< items\ to\ send >$ $< item\ size >$ $< interval >$ $< start\ time >$ $< end\ time >$

where

$< src >$ is the client node. $< dest >$ is the server node. $< items\ to\ send >$ is how many application layer items to send. $< item\ size >$ is size of each application layer item. $< interval >$ is the interdeparture time between the application layer items. $< start\ time >$ is when to start CBR during the simulation. $< end\ time >$ is when to terminate CBR during the simulation.

If $< items\ to\ send >$ is set to 0, CBR will run until the specified $< end\ time >$ or until the end of the simulation. If $< end\ time >$ is set to 0, CBR will run until all $< items\ to\ send >$ are transmitted or until the end of simulation. If

< *items to send* > and < *end time* > are both greater than 0, CBR will run until either < *items to send* > is done, < *end time* > is reached, or the simulation ends.

5.3 Scenarios

We have organized the simulation into two parts: part one shows the performance of the protocol when flood depth and HELLO transmission time are varied. While part two is a performance study for different scenarios that target the performance upper bounds as well as scenarios that reflect practical applications of MANETs. In part two we compare the performance of Partial Flooding with that of ODMRP, and Flooding for the same simulation configurations, see Table 5.2. Results obtained for ODMRP and Flooding were verified with that obtained in [24, 28, 33].

Each simulation (keeping all parameters constant) is ran for five times, each time using a different seed. Seeds are varied from 1000 to 5000 in steps of 1000. Each data point in the results graphs represents the average across all five runs. In all experiments members as well as senders are chosen and placed randomly in the terrain range. Each node moves according to the *random waypoint* model, where mobility speed is set between 0 and 150 km/h.

Parameter	Value	Description
number of nodes	50 nodes	nodes in simulation model
num − packets	10 - 40 pps	packet rate of a typical source
field range − x	1000 m	X - dimension of motion
field range − y	1000 m	Y - dimension of motion
power range	250 m	node's power range
bandwidth	2 Mbit/s	channel capacity
simulation time	500 sec	simulation duration
node placement	random	node placement policy
speed range	0 - 150 Km/h	max and min node speeds
pause time	0 - 10 sec	pause time of nodes at the current location
propagation func.	Free-Space	propagation function
mac protocol	IEEE 802.11	MAC layer protocol
transport protocol	UDP	transport protocol

Table 5.2: Typical Simulation Parameters.

Parameter	Value
JOIN DATA refresh interval	3 sec
Acknowledgement timeout for JOIN TABLE	25 msec
Maximum JOIN TABLE retransmission	3

Table 5.3: Parameter Values for ODMRP.

Parameter	Value
JOIN DATA refresh interval	5 sec
Acknowledgement timeout for JOIN TABLE	25 msec
HELLO interval	1.2 sec
Flood Diameter	3

Table 5.4: Parameter Values for Partial Flooding.

5.3.1 Flood Depth

This experiment is intended to measure the effect of varying the flood depth, which is the maximum hops that flooded multicast packets can traverse. Setting the appropriate value of this parameter is important since a low value might not improve the performance substantially and large values might degrade the performance. The ZRP [16] uses a similar approach in specifying the maximum hops that state information can traverse.

In this experiment a single node sends data at a rate of 20 pps. There are 20 multicast group members. Flood depth is varied in the set of {3, 5, 7} hops.

As shown in Figure 5.1, packet delivery ratio increases as flood depth increases. However, at flood depth of 7, packet delivery ratio degrades. This is due to the redundant transmissions which increase collisions and hence packet loss goes down. Flood depth of 5 gives the best results. However, these results do not apply for all simulation scenarios. Most of the upcoming experiments used a flood depth of 3 hops, which gave better results for most of them.

Figure 5.2 shows the total number of packets transmitted per data packet delivered. As expected, this value increases as flood depth increases. Flood depth of 7 hops introduced the highest overhead, while that of 5 hops falls between those for 7 and 3 hops. Note that at speed of 3.6 km/h total number of packets transmitted per data packet delivered increased due to the random number generator's seed.

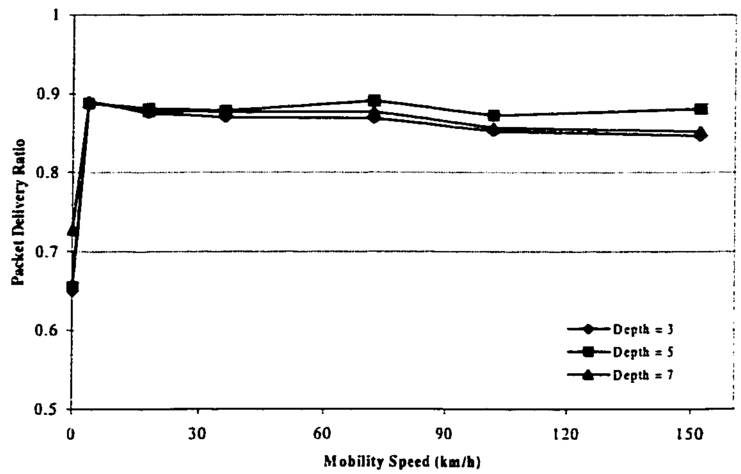


Figure 5.1: Packet Delivery Ratio as a Function of Mobility Speed (flood depth change).

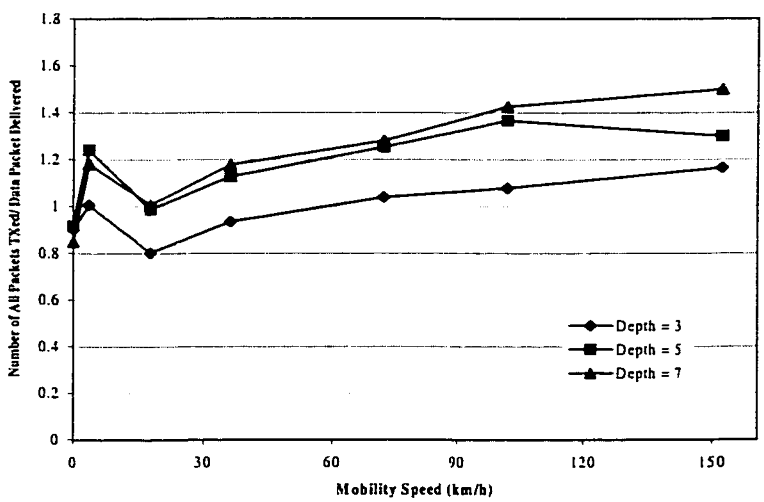


Figure 5.2: Number of All Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (flood depth change).

5.3.2 Beaconing Time

In this experiment we study the effect of the frequency and start time of sending HELLO packets by *forwarding group* nodes to their neighbors. Beaconing time was chosen from the set of {0.6, 1.2, 1.8} Sec. We investigated that taking in mind the JOIN DATA refresh interval, see Table 5.4. There are 5 senders and 20 member nodes. Network traffic load was set to 20 pps.

Results of this experiment show that the time when HELLO packets are transmitted and the frequency of their transmission have a large impact on the performance of our scheme. In Figure 5.3, packet delivery ratio degrades rapidly when beacon time is 0.6 Sec. This high frequency of transmission causes more collisions (Figure 5.5) and increases the total number of packets transmitted per data packet delivered (Figure 5.4). This happen due to the large number of dropped data packets, while control transmissions are high.

However, at beacon time (1.2 Sec and 1.8 Sec) the performance is much better and we observe a packet delivery ratio of over 90% (Figure 5.3). The total number of packets transmitted per data packet delivered is far below that obtained with 0.6 Sec (Figure 5.4). This low number of transmissions results in less number of collisions (Figure 5.5). In fact, this behaviour again depends on the configuration. On the basis of many scenarios, 1.2 Sec beacon time shows a more stable and better performance than that produced when beacon time is 1.8 Sec or more.

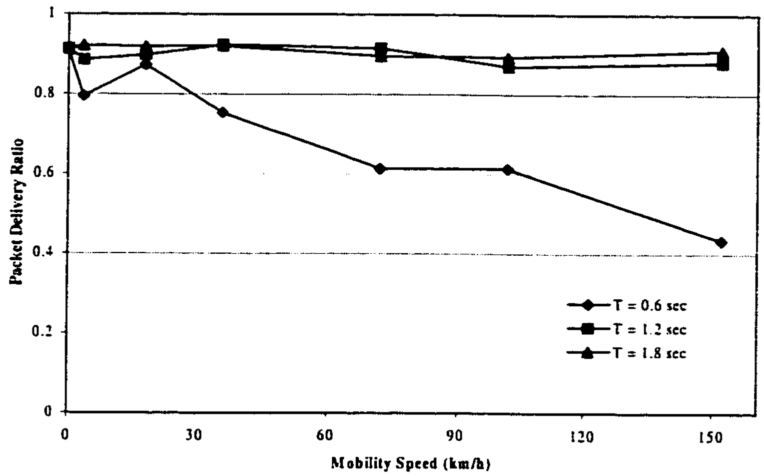


Figure 5.3: Packet Delivery Ratio as a Function of Mobility Speed(beacon time change).

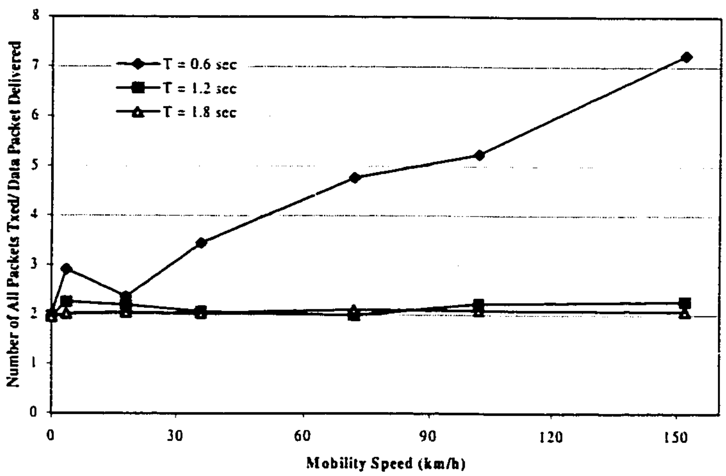


Figure 5.4: Number of All Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (beacon time change).

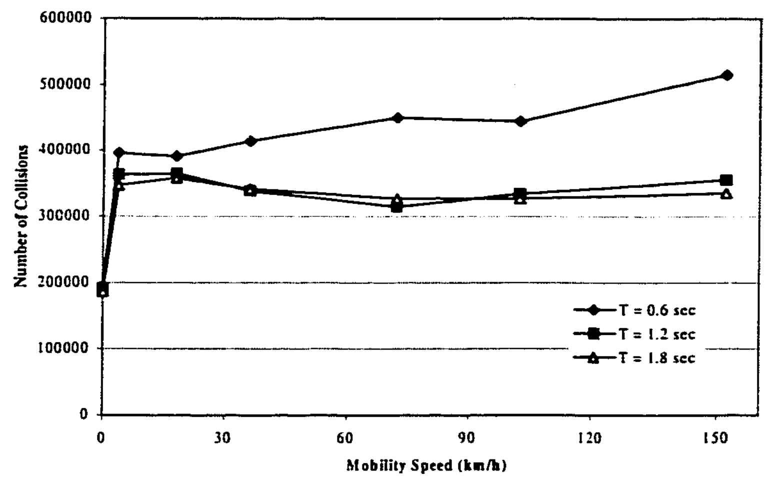


Figure 5.5: Number of Collisions as a Function of Mobility Speed (beacon time change).

5.3.3 Single Sender

In this experiment a single multicast group of a single sender and a group of members ranging in the set of {5, 20} members is simulated. Network traffic load is 10 pps. Class lecture applications, in which a single node sends data is an example of this scenario. It exploits the ability of the protocol to handle situations where the number of senders and receivers is very small.

The single sender scenario shows that our scheme outperforms ODMRP. When 5 nodes are multicast members, the multicast mesh created do not have a rich connectivity which makes receiver nodes to move out of transmission range of their upstream nodes and hence the packet delivery ratio is low. However, Partial Flooding shows a very steady high performance compared to what obtained by ODMRP since nodes that move out of transmission range will trigger the flooding process to ensure high delivery ratio over all mobility speeds (Figure 5.6). However, when 20 nodes are multicast members (see Figure 5.10) the mesh created is richer than that created when there are 5 members, hence packet delivery ratio is high for both schemes. But still Partial Flooding shows a less performance degradation than ODMRP. Flooding is more robust and it shows a higher performance than other protocols for both scenarios.

Number of data packets transmitted per data packet delivered is shown in Figures 5.8 and 5.12 and number of all packets transmitted per data packet delivered is shown in Figures 5.9 and 5.13. When there are 5 group members, the number of data packets transmitted and all packets transmitted per packet delivered in Partial Flooding is less than that for Flooding and ODMRP. Flooding shows the highest value since all nodes in the network forward the same data packet once.

Figures 5.7 and 5.11 shows the control byte overhead per data byte delivered. Since Flooding has no control packets, only the data header contributes to control overhead and this overhead does not increase with mobility for both 5 members and 20 members. ODMRP and Partial Flooding generate higher control overhead than Flooding. In the 20 members scenario, Partial Flooding generates higher packet transmissions than ODMRP. This is due to the redundant flooding while the mesh created is already rich. But still the control overhead is reduced.

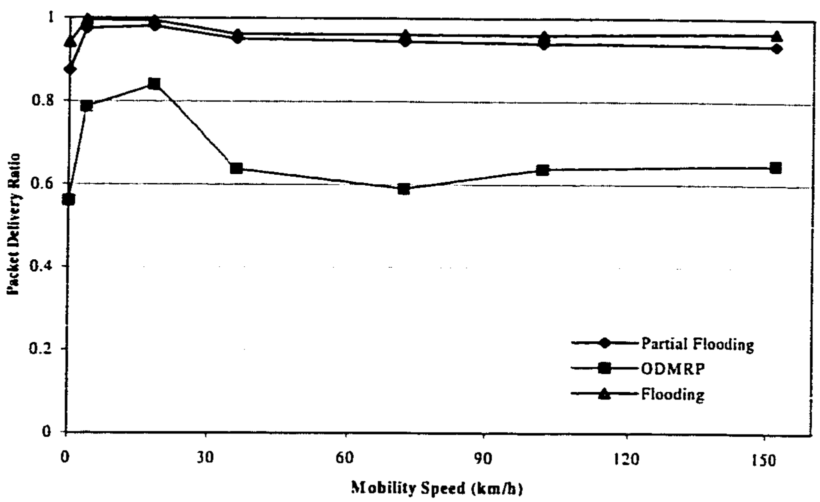


Figure 5.6: Packet Delivery Ratio as a Function of Mobility Speed (single sender, 5 members).

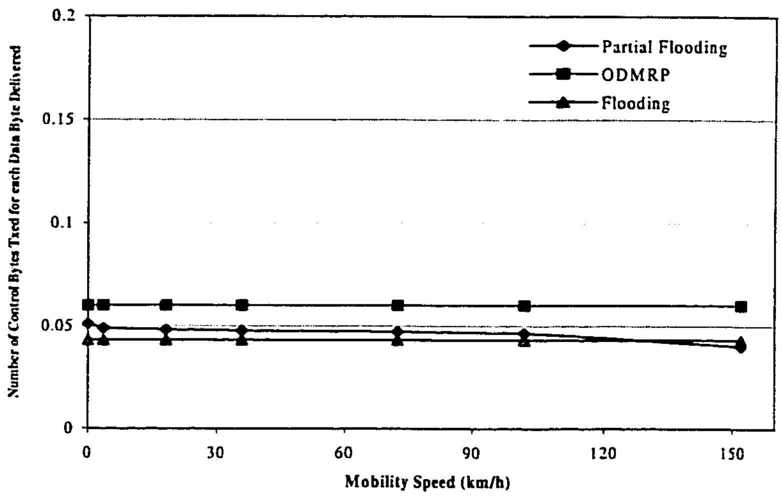


Figure 5.7: Number of Control Bytes Transmitted per Data Byte Delivered as a Function of Mobility Speed (single sender, 5 members).

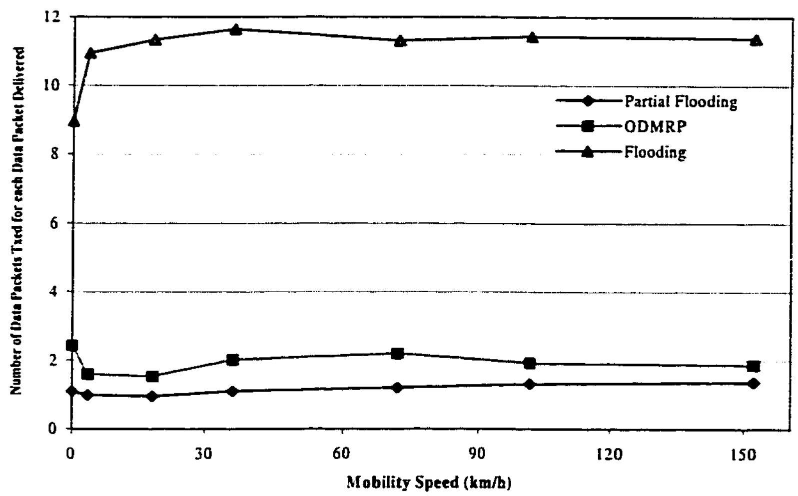


Figure 5.8: Number of Data Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (single sender, 5 members).

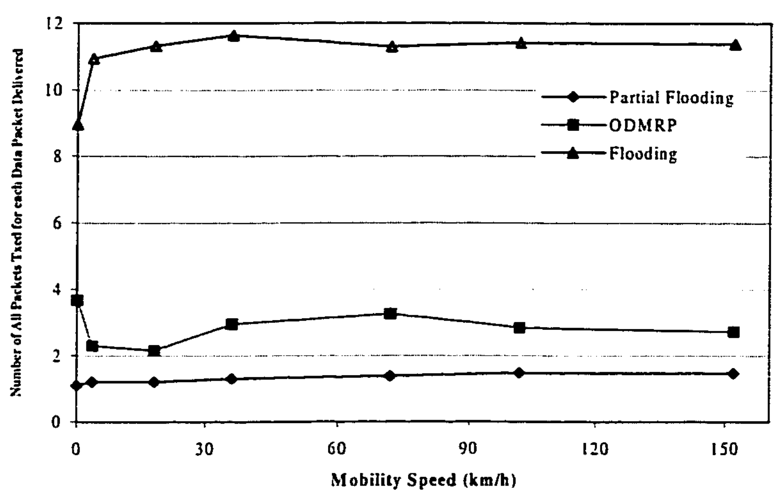


Figure 5.9: Number of All Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (single sender, 5 members).

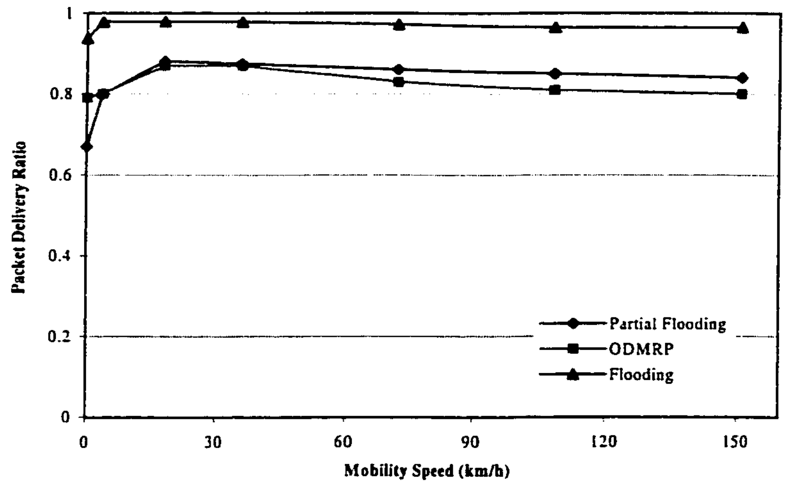


Figure 5.10: Packet Delivery Ratio as a Function of Mobility Speed (single sender, 20 members).

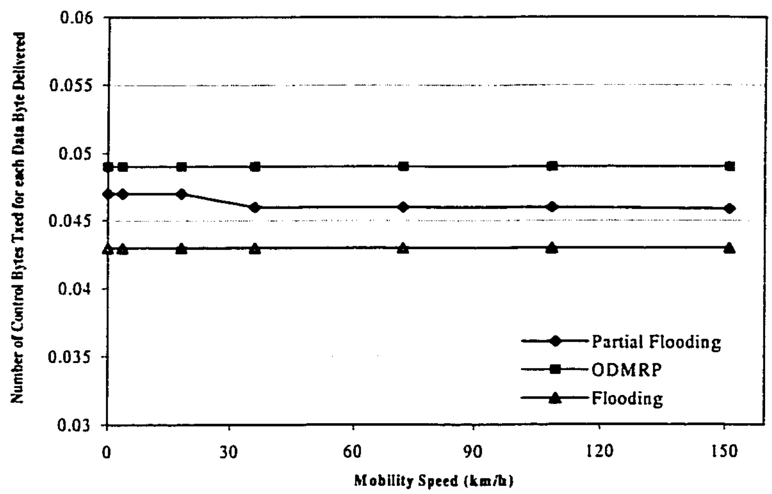


Figure 5.11: Number of Control Bytes Transmitted per Data Byte Delivered as a Function of Mobility Speed (single sender, 20 members).

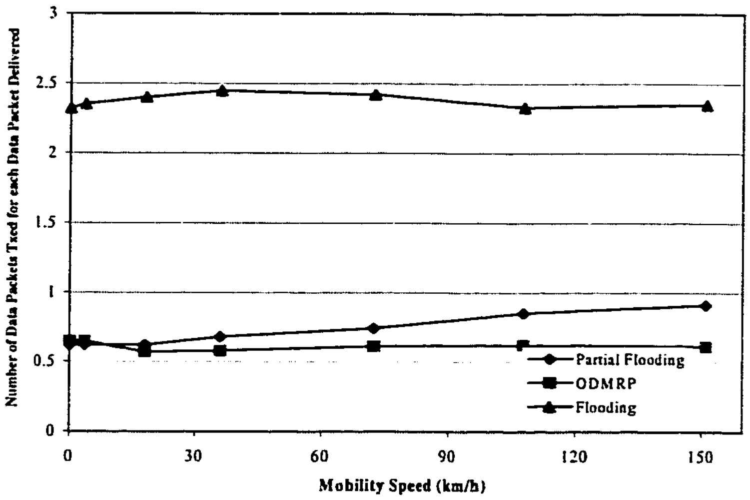


Figure 5.12: Number of Data Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (single sender, 20 members).

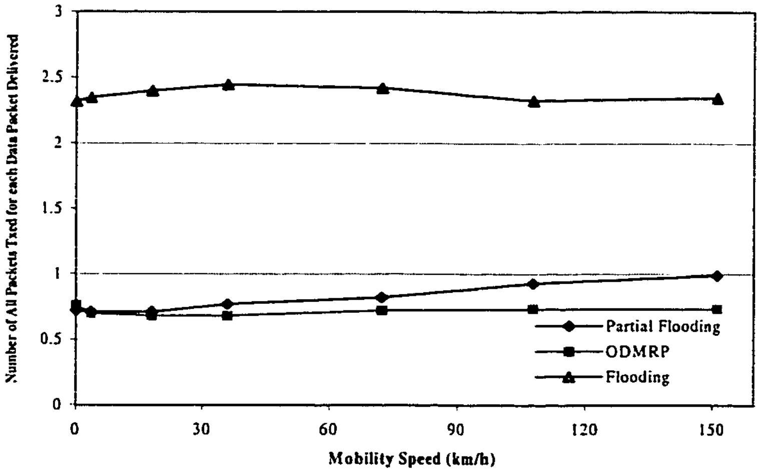


Figure 5.13: Number of All Packets Transmitted per Data Packet Delivered as a Function of Mobility Speed (single sender, 20 members).

5.3.4 Multiple Senders

In this experiment, the multicast group size is set constant at 20, and network traffic load is relatively light (10 pps). The multicast senders range in a set of {5, 10, 20} senders. The 20 senders case can model a video conference situation.

Figures 5.14 to 5.19 show the performance of Partial Flooding, ODMRP, and Flooding in different cases of a video conference application. At the 5 and 10 senders case, the performance of all protocols is high (over 95%). However, at 20 senders scenario, ODMRP performance degrades because of the higher control packets generated. In this case all multicast senders generate periodic JOIN REQUEST(s) at higher frequency than for Partial Flooding, which subsequently triggered more transmissions of JOIN TABLE(s) and ACK(s). These transmissions cause more collisions and hence packet delivery ratio is low while overhead is high.

Control bytes transmitted per data byte delivered, data packets transmitted per data packet delivered, and all packets transmitted per data packet delivered are averaged over all mobility speeds and shown in Figures 5.17, 5.18, and 5.19. Flooding generates a lower control overhead than ODMRP and Partial Flooding since only packet header contributes to that. ODMRP has a higher JOIN DATA transmission frequency, hence it generates the highest number of all packets and data packets transmissions per data packet delivered. ODMRP generates packets twice as much as that generated by Flooding and Partial Flooding when there are

20 senders.

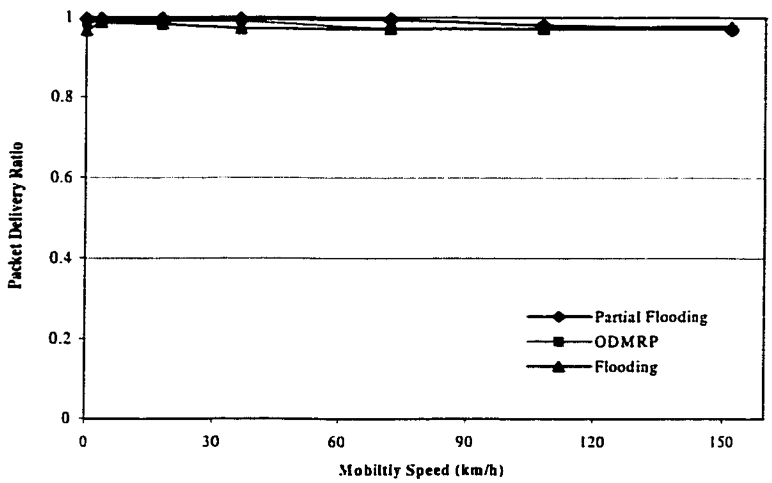


Figure 5.14: Packet Delivery Ratio as a Function of Mobility Speed (5 senders).

5.3.5 Multicast Group Size

Multicast group size is varied to investigate the scalability of the protocols. The senders are fixed to 5, network traffic load rate is 10 pps, and the multicast group size was varied in a set {5, 10, 20, 40, and 50} members.

The results in Figures 5.20 to 5.24 show that all schemes have high packet delivery ratio at all mobility speeds. This is expected due to the high redundancy in the multicast mesh in case of ODMRP and Partial Flooding. However, it is observed, that at all cases, ODMRP generates higher control overhead than both Flooding

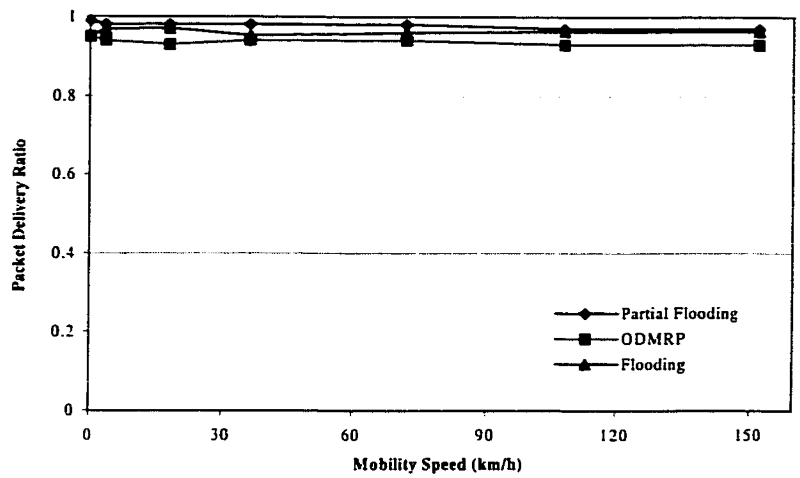


Figure 5.15: Packet Delivery Ratio as a Function of Mobility Speed (10 senders).

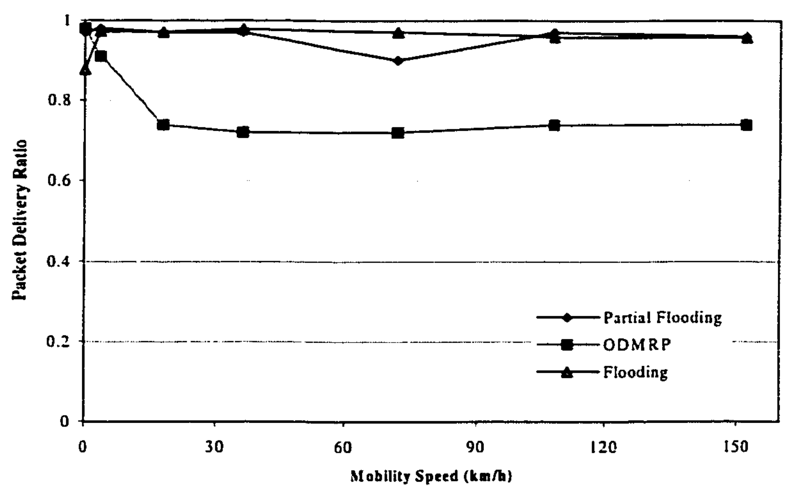


Figure 5.16: Packet Delivery Ratio as a Function of Mobility Speed (20 senders).

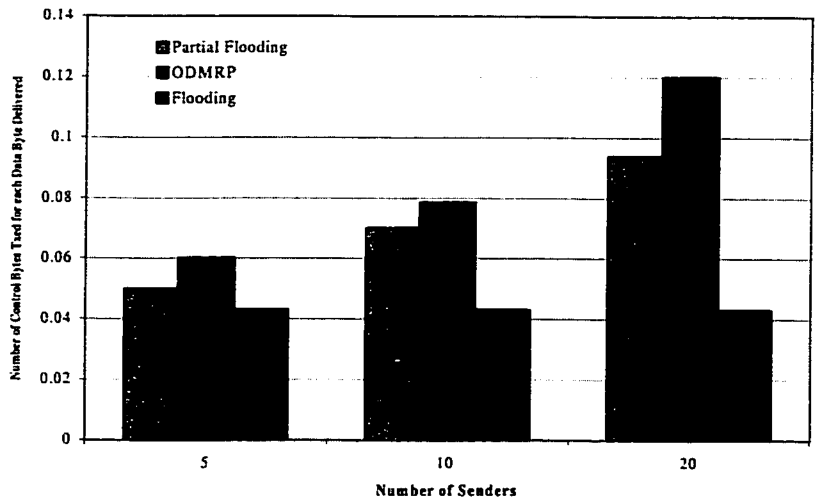


Figure 5.17: Average Number of Control Bytes Transmitted per Data Byte Delivered over all Mobility Speeds as a Function of Number of Senders (20 senders).

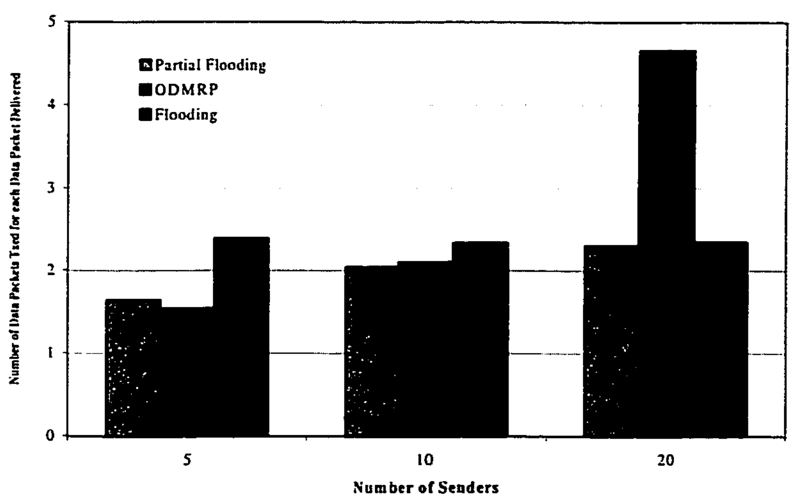


Figure 5.18: Average Number of Data Packets Transmitted per Data Packet Delivered over all Mobility Speeds as a Function of Number of Senders.

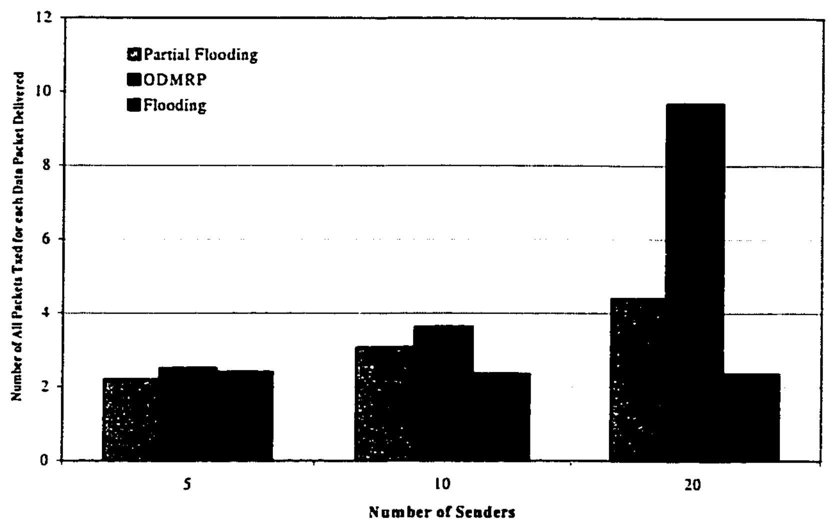


Figure 5.19: Average Number of All Packets Transmitted per Data Packet Delivered over all Mobility Speeds as a Function of Number of Senders.

and Partial Flooding (see Figure 5.25). This is caused by the higher frequency of transmitting control packets.

Number of data packets transmitted per data packet delivered is shown in Figure 5.26, and Number of all packets transmitted per data packet delivered is shown in Figure 5.27. Flooding generates the highest number of data and all packets transmissions when there are 5 members in the multicast group. The primary reason is that it generates a lot of redundant transmissions since all nodes in the network transmit the same packet at least once. However, when all nodes are members, Flooding generates the minimum number of packet transmissions. Partial Flooding also produces less number of transmissions than ODMRP at various group sizes.

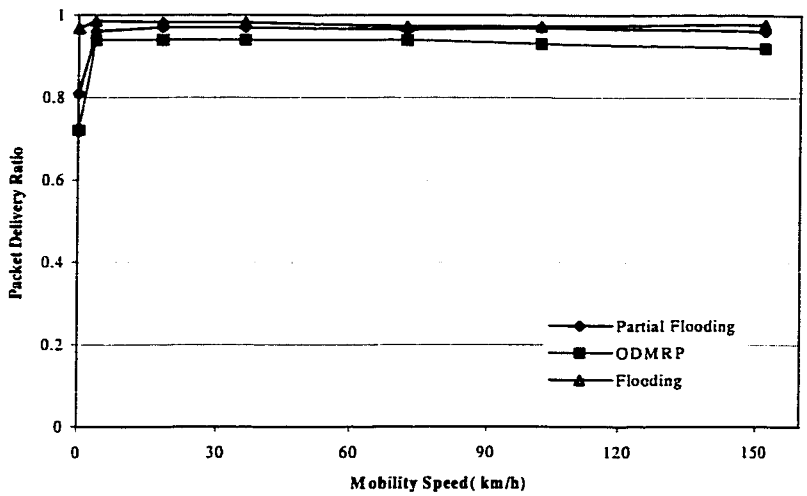


Figure 5.20: Packet Delivery Ratio as a Function of Mobility Speed (5 members).

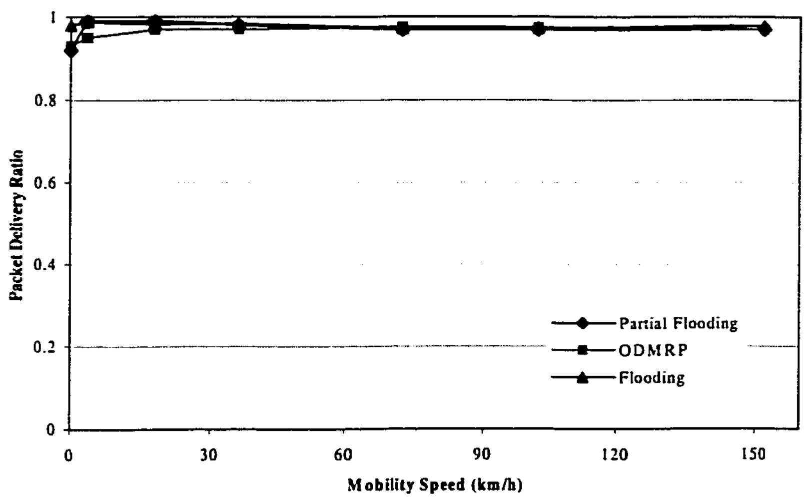


Figure 5.21: Packet Delivery Ratio as a Function of Mobility Speed (10 members).

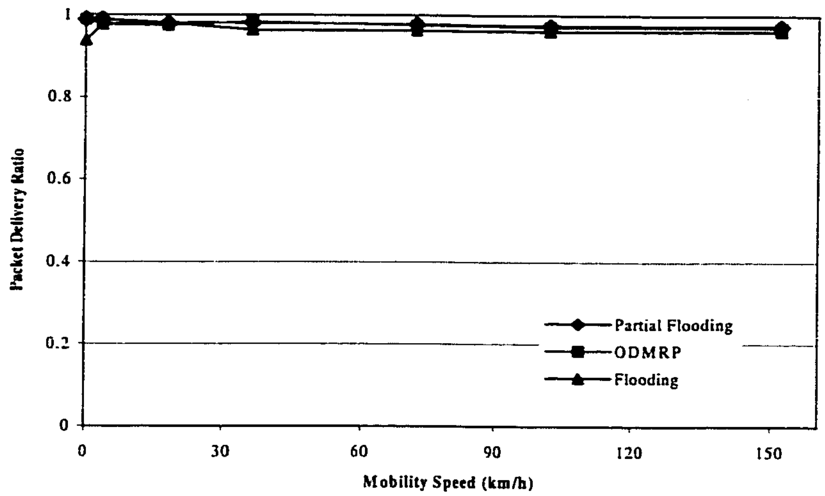


Figure 5.22: Packet Delivery Ratio as a Function of Mobility Speed (20 members).

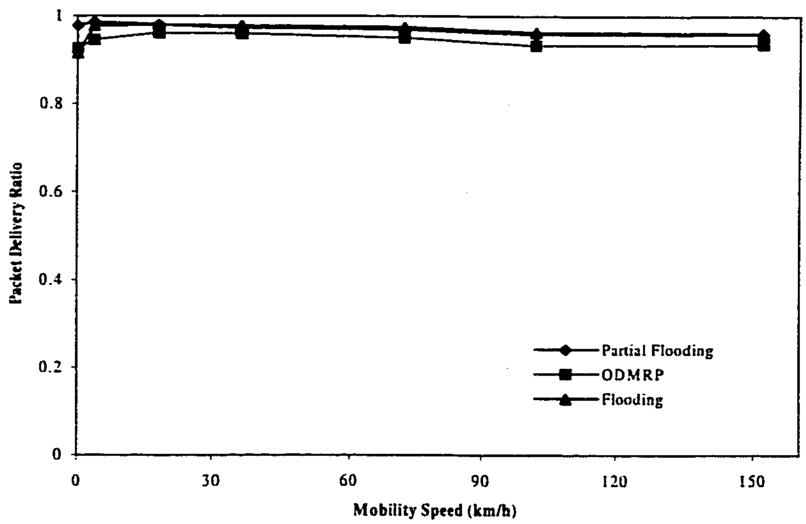


Figure 5.23: Packet Delivery Ratio as a Function of Mobility Speed (40 members).

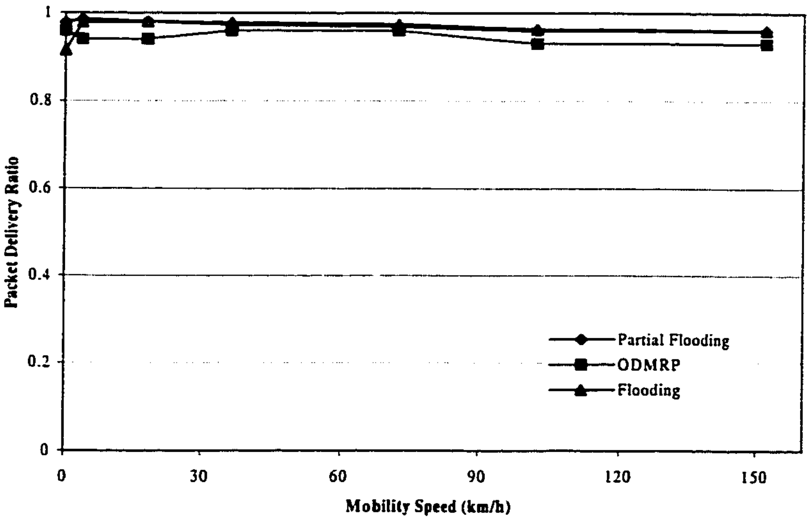


Figure 5.24: Packet Delivery Ratio as a Function of Mobility Speed (50 members).

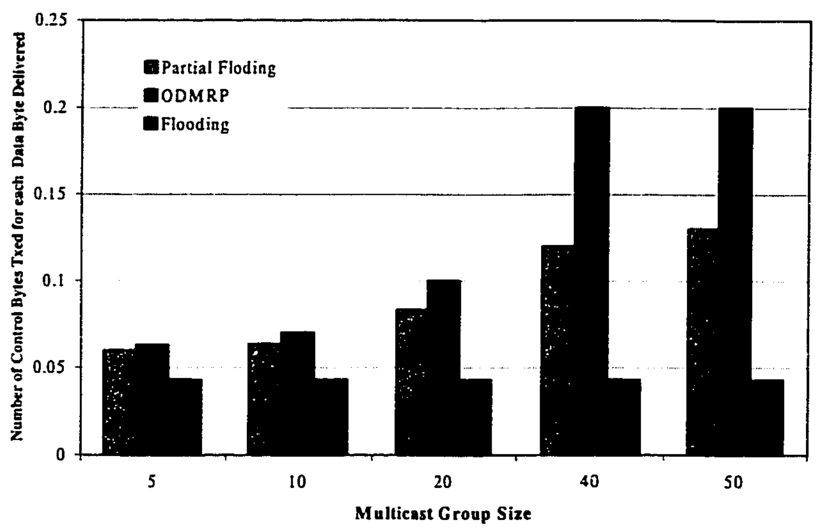


Figure 5.25: Average Number of Control Bytes Transmitted per Data Byte Delivered over all Mobility Speeds as a Function of Multicast Group Size.

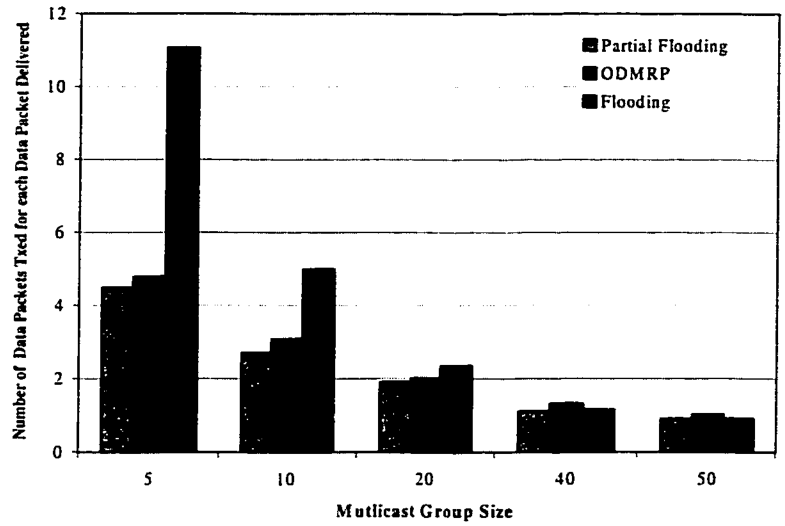


Figure 5.26: Average Number of Data Packets Transmitted per Data Packet Delivered over all Mobility Speeds as a Function of Multicast Group Size.

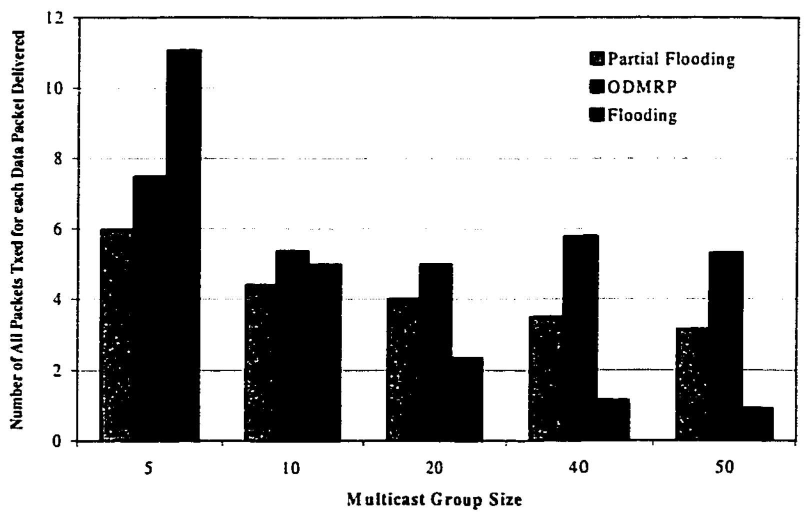


Figure 5.27: Average Number of All Packets Transmitted per Data Packet Delivered over all Mobility Speeds as a Function of Multicast Group Size.

5.3.6 Network Traffic Load

Investigating the impact of network traffic load is important to measure robustness and scalability of the scheme. This experiment simulates 5 senders and a multicast group of 5 members. Network traffic loads were varied in a set of {20, 30, 40} pps.

It is clear from both Figures 5.28 and 5.29 that Partial Flooding is considerably providing a better packet delivery ratio than ODMRP at all mobility speeds when network traffic load is between 20 pps and 30 pps. While at 40 pps traffic rate (Figure 5.30) performance improvement is not significant which is due to the collisions caused by HELLO packets transmissions. However, those collisions are less than those caused by the higher frequency of route refresh packets (JOIN REQUEST and JOIN TABLE) in case of ODMRP.

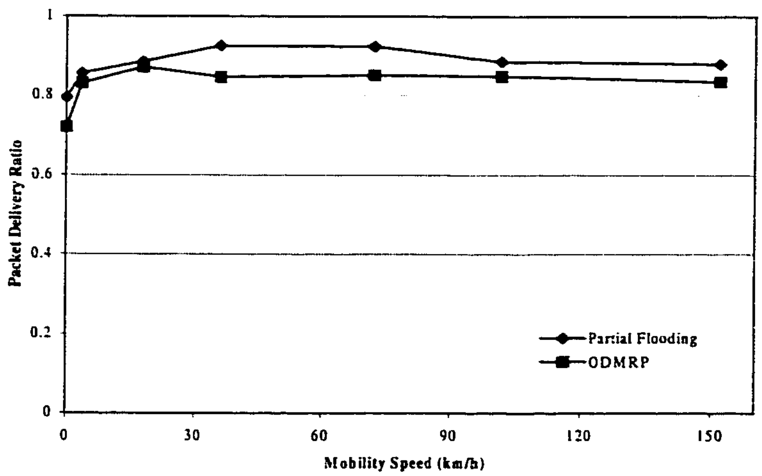


Figure 5.28: Packet Delivery Ratio as a Function of Mobility Speed (20 pps).

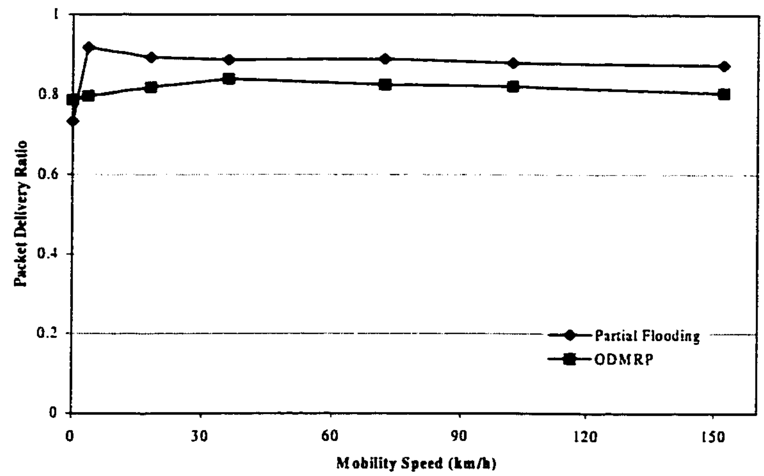


Figure 5.29: Packet Delivery Ratio as a Function of Mobility Speed (30 pps).

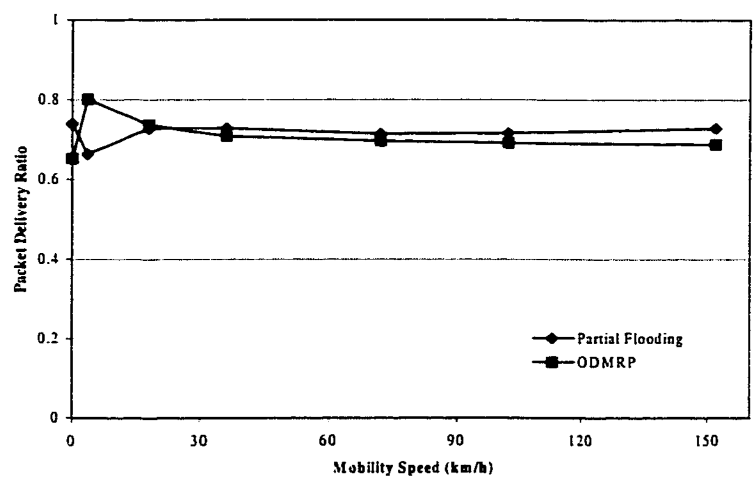


Figure 5.30: Packet Delivery Ratio as a Function of Mobility Speed (40 pps).

Chapter 6

Conclusion

6.1 Summary

In this work we have discussed multicast routing for MANETs and issues related to routing techniques in these networks. We have also proposed a multicast routing protocol, which was evaluated and compared with ODMRP and Flooding.

Background about MANETs, their design goals, and all issues related to mobile nodes and application of these networks is given in Chapter 1. In MANETs there is no distinction between a host and a router because all network hosts can be endpoints as well as routers. Nodes in these networks move arbitrarily, thus network topology changes frequently and unpredictably. Design of routing and multicasting in MANETs must consider four general guidelines: Robustness versus efficiency, active adaptability, unlimited mobility and integrated multicast.

Chapter 2 briefly discussed MANETs routing algorithms and their classification. Two categories of ad hoc multicast routing protocols have been investigated, proactive protocols and reactive protocols. Proactive protocols attempt to continuously determine the network connectivity so that the route is already available when a packet need to be forwarded. While, reactive protocols, in contrast, invoke a route discovery procedure only on demand, i.e., when a packet needs to be sent.

Membership and maintenance techniques (Sender Advertisement and Receiver Advertisement) are also discussed in Chapter 2. It was stated that the Sender Advertisement scheme gives better performance than the other.

ODMRP (Chapter 3) was the basic technique that we adopt as a constructive multicast routing protocol based on the forwarding group concept. It falls into the category of on-demand protocols since group membership and multicast routes are established and updated by the source whenever it has data to send. In contrast to $tree - based$ multicast protocols, ODMRP builds a multicast mesh to avoid drawbacks of multicast trees in mobile networks, e.g., frequent tree reconfiguration.

Chapter 4 discussed our new approach for multicast routing in mobile ad hoc networks. The scheme follows the on-demand $forwarding\ group$ approach, and occasionally utilizes limited flooding. It utilizes global control messages sent by the source node to refresh the multicast group members and route information, as well as local beacon messages sent by all forwarding nodes to determine the current mobility state of their downstream nodes. These beacon messages are used by forwarding nodes to detect when downstream nodes move out of their transmission range, and therefore switch to flooding.

Performance analysis have been conducted using GloMoSim simulation library. Results shown in Chapter 5 shows that our scheme outperform ODMRP for most simulation scenarios. In the singe sender and 5 members case ODMRP does not perform well since the created mesh has a weak connectivity and packet loss is high. However, in Partial Flooding, movements of node trigger the flooding and packet delivery ratio is about 95%. In addition to that, Partial Flooding generates lesser control and transmission overhead than ODMRP. Flooding is better than these two protocols in terms of packet delivery ratio and control overhead but it generates a larger number of packet transmissions.

Varying the number of senders shows that Partial Flooding is more efficient and generates lower control and transmission overhead than ODMRP. Obtained results for Flooding is almost identical to that of Partial Flooding in this scenario.

Multicast group size was varied to investigate the scalability of the protocols. Results show that Partial Flooding is more scalable than ODMRP. It results in a similar packet delivery ratio (more than 90%) and at the same time control overhead and number of packet transmissions is highly reduced, specially when all network nodes are members. Flooding does not perform well when there are small number of receivers.

Experiments on the impact of network traffic load on multicast protocols show that Partial Flooding delivers more than 90% of data packets, while ODMRP delivers about 85% when network traffic load is between 20 pps and 30 pps. At 40 pps network traffic load both protocols deliver about 73%. This reduction is caused by the small packet interdeparture time, which subsequently increases collisions.

6.2 Future Research

Our future work will be on how to dynamically adapt the transmission time of HELLO packets to minimize transmission and control overhead. Other multicast routing protocols that are based on the forwarding group concept (e.g., FGMP, NSMP, CAMP) can be used as constructive protocols and flooding is integrated with them.

QoS multicast routing is also an important topic in MANETs and it will be investigated in our future research.

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