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CROSS-LAYER OPTIMIZATION OF AD HOC ON-DEMAND DISTANCE VECTOR
ROUTING PROTOCOL

by

Ali Bidabadi

A Thesis
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ABSTRACT

In this thesis, the problem of flooding in wireless ad hoc reactive routing protocols is addressed. The flooding approach is employed for the route discovery phase, during which query packets are broadcasted throughout the entire network. Since transmission capacity is a scarce resource in wireless networks, flooding consume large portion of useful bandwidth in any wireless communication system.

In the proposed scheme, the two following methods are used to reduce flooding messages:

1) Nodes are classified as Mobile Nodes (MNs) and Forwarding Nodes (FNs), with each responsible for different functionalities.

2) The Contention Window (CW) in wireless MAC layer (IEEE 802.11) has been employed to optimize routing decisions.

The AODV routing protocol is modified to exploit the above-mentioned methodologies. The proposed models are simulated using NS-2. They are then compared to regular AODV.

Finally, it is shown via simulations that combining both models further improves performance of the network.

DEDICATION

This thesis is dedicated to my beloved family, whom I feel blessed to be part of. Their never-ending encouragement, faithful support and continuous feel of security were the greatest gifts I can ask for.

ACKNOWLEDGEMENTS

First, I would like to express the deepest appreciation to my supervisor Dr. Kemal Tepe for his assistance, guidance and continuous support. I have benefited tremendously from his extensive knowledge and technical insight. Without him, I would have not been able to complete my thesis.

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Finally, I thank God for everything. Thanks for providing my home, my friends and the journey that He has planned for my life.

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CHAPTER I

INTRODUCTION

1.1 Mobile Ad Hoc Networks: Issues and Challenges

A mobile ad hoc network (MANET) is a collection of wireless mobile nodes that can freely self-organize in network topologies without the existence of an infrastructure or a centralized administration. Mobile wireless networking has drawn tremendous popularity over the last several years, since it offers unique benefits and versatility for certain applications. They can be originated and used anywhere and anytime because no fixed infrastructure including base stations exists in such networks. Furthermore, insertion of new mobile nodes or deletion of a current terminal can take place only by interactions with the other existing nodes. In other words no other entity such as a central agent is involved in any of those operations [26].

These perceived advantages attracted immediate and remarkable interests in the early days among military people, rescue organizations and many other agencies where disorganized or hostile conditions exist. These conditions include armed conflict in the battlefields or isolated areas of natural disaster. Vehicular Ad Hoc Networks (VANET) is another area of application that recently has seen a phenomenal growth. Small vehicular devices equipped with cameras can also be deployed at certain regions to collect environmental and location information which can be transmitted back to a processing agent via mobile ad hoc communications. Moreover, wearable wireless devices can be used by members of the rescue team for the purpose of relaying information via data,

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voice or video to the other members of the same team who are probably at different locations. So far only small-scale mobile ad hoc networks have started to appear in the public market. On the other hand wide area ad hoc networks which are multihop wireless networks are increasingly drawing attentions of the research community. We can regard personal digital assistants and laptop computers as mobile nodes in a wireless multihop network [26].
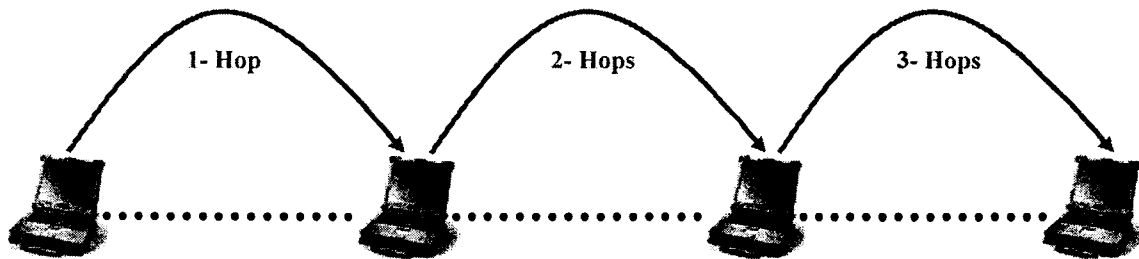
Figure 1.   A multihop mobile ad hoc network

Although flexibility, robustness, ease of deployment and inherent support for mobility are major advantages of wireless ad hoc networking, there remain many challenges in deploying an ad hoc network. We can summarize some of those challenges as follows:

1. Constrained power: Due to portable nature of mobile nodes in MANETs, limitations on power consumption in such environment is an unarguable fact. Thus nodes should be energy conserving to maximize the battery life. Given this

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fact, many researchers have recently focused on designing routing protocols in which energy level of mobile nodes in the network is taken into consideration.

2. Limited bandwidth: Compared with broadband wired networks, common data rates in wireless environment rarely exceeds 11mbps. Such low bandwidth wireless networks may become a huge problem when applications with high bandwidth requirement are concerned. Widespread use of reactive routing protocols in wireless ad hoc environment, highlights the significance of the bandwidth issue.

3. Mobility: Dynamic network structure and topology is an important issue in ad hoc networks with mobile nodes, where nodes can easily leave or join the network without a prior notification. In MANETs, nodes are allowed to freely move and therefore breaking some routes in the network. Again this presents a momentous challenge to the routing protocols.

4. Security: Two major issues in MANETs, highlight the security threats when compared to the security vulnerabilities of wired networks: lack of a centralized authority and use of a shared medium in wireless networks. Most of the security measures today rely on the existence of a centralized authority. Moreover, transmission over a shared medium in wireless environments makes the data traffic susceptible to attacks such as signal interferences.

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1.2 Cross-Layer Design

As wireless networking becomes more and more popular, the unsuitability of the layered architecture such as OSI seven-layer model for wireless networks is drawing attentions of the research community. Many has argued that although layered models have satisfied the basic needs of wired networks, they may not be appropriate for wireless environments. To address this issue, many researchers have proposed what they usually refer to as a cross-layer design approach. Recently a considerable number of cross-layer design methodologies have been under investigation. In [25] Srivastava and Motani have defined the cross-layer design as "protocol design by the violation of a reference layered communication architecture with respect to the particular layered architecture". Unlike the layered architecture, where protocols at the different levels operate independently, cross-later schemes exploit dependence between layers to improve and optimize the performance of the wireless networks. One issue that should always be remembered when conducting research in this area is the problem of modularity in the sense that one may see the potential loss of modularity in cross-layer design [25].

The authors in [22] have suggested that due to inflexibility of the layered models, a cross-layer design approach such as the one shown in Figure 2. , which supports adaptivity and optimization across multiple layers of the protocol stack, should be considered.

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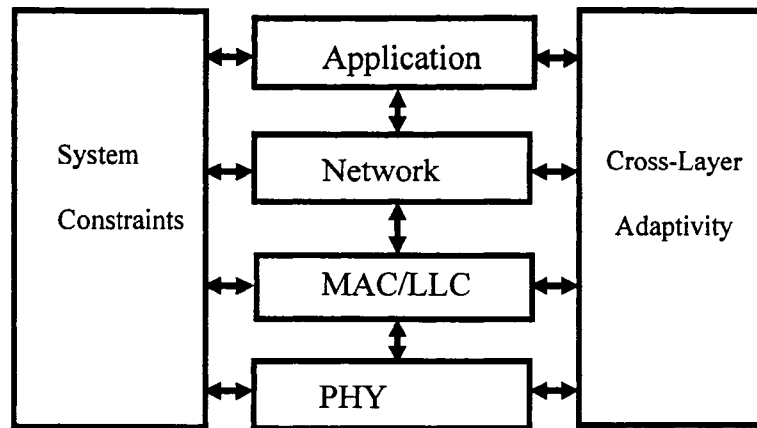
Figure 2.   An adaptive cross-layer protocol design

In order to design a protocol stack based on Figure 2. , we need to know what information should be exchanged among protocol layers. Furthermore another question must be answered in this regard: How can we force system constraints into the protocol designs at each layer?

The authors in [25] have explained some of their observations in the area of cross-layer design. First, there are several explanations of cross-layer design. The main reason is that during the past years researches in this area have not been coordinated by a central committee. Also, many of the cross-layer design researchers have different backgrounds and work on different layers of the protocol stack. Another observation that was made by those authors is the fact that synergy between the implementation viewpoint and performance concern is not strong enough. In other words most of the current proposals concentrate on the performance gains from cross-layer design, while few ideas on implementing cross-layer design interactions have been proposed.

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Finally, there remain many open questions to be answered in the understanding, performance and implementation of the cross-layer design philosophy. In the next chapter, a selective related literature is presented.

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1.3 Thesis Organization

The rest of this thesis is organized as follows. Chapter II defines the problem and provides a survey of the flooding problem in reactive ad hoc routing protocols as well as cross-layer design related studies. Chapter III explains the proposed scheme to alleviate the flooding problem and how it can be tackled from a cross-layer design viewpoint. Simulation results along with our analysis of the results are exhibited in Chapter IV. Finally, Chapter V draws conclusions of this thesis and recommends potential future works in our research.

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CHAPTER II

BACKGROUND, LITERATURE REVIEW AND PROBLEM

2.1 Routing Protocols in Mobile Ad Hoc Networks

Research on routing protocols in multihop wireless ad hoc networks dates back to

1973, when the packet radio network (PRNET) project was established [28]. PRNET

generated a considerable number of fundamental results in this area. With the

development of smaller, more powerful and portable computers, an increasing number of

other research projects in ad hoc network environment have developed. Existing mobile

ad hoc routing protocols mainly use one of the following two approaches: 1) Position-

based routing and 2) Topology-based routing [26].

Position-based routing protocols use the actual geographic location of nodes to make

routing decisions. Position information can simply be obtained through some positioning

mechanism such as Global Positioning System (GPS). Since there is not much

relationship between this approach and our problem of special interest, we have not

presented a review of location-based routing protocols in this work.

In contrast to position-based approaches, a topology-based scheme uses the knowledge of

instantaneous connectivity of the network with consideration of network links. Topology-

based routing protocols can largely be classified into the following three categories:

Proactive (Table-driven), Reactive (On-demand), and Hybrid.

In an ad hoc environment where a proactive routing protocol is employed, nodes

calculate all possible paths to all destinations. Each node maintains a routing table that is

formed using either link-state or distance-vector routing algorithm. As shown in Figure 3.

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the Destination-Sequenced Distance Vector (DSDV) routing protocol and the Wireless

Routing Protocol (WRP) are two well-known examples of proactive routing protocol.

These protocols require constant propagation of routing information and as a result they

cause high battery consumption and network congestion. That is why pure proactive

schemes may not be an appropriate model for an ad hoc environment with a large number

of nodes.
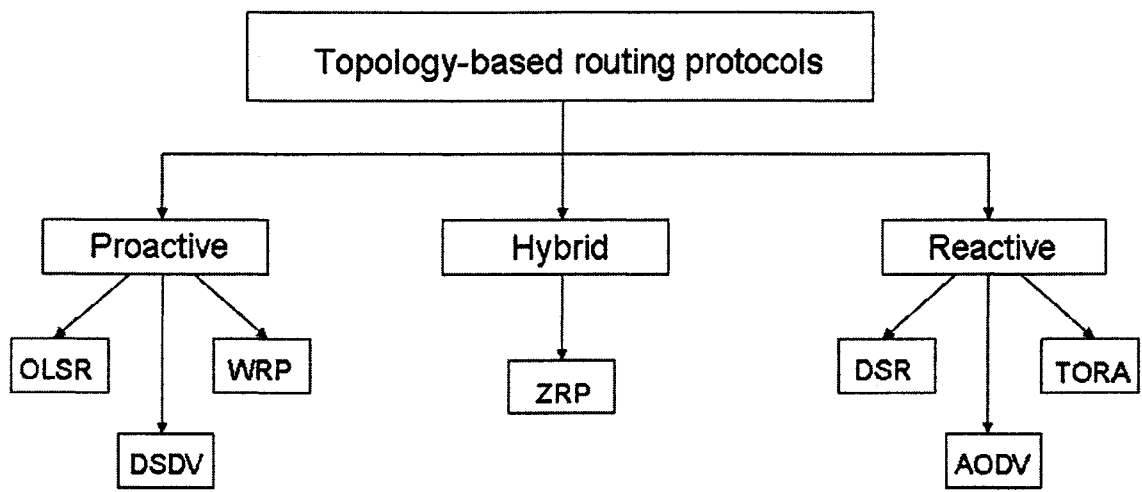
Figure 3.   Categorization of mobile ad hoc routing protocols

The philosophy behind reactive routing protocol such as DSR [1], is to obtain routing

information only when they are needed. These schemes consist of two procedures: route

discovery and route maintenance. During the route discovery procedure, the source node

floods the network with a route request packet to discover a path to its desired

destination. Upon receiving the request, the destination sends a reply including its address

back to the source node. Throughout the data transmission phase, routing information is

retained by a maintenance procedure until either the communication ends or an error on

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the forwarding path occurs. Although both routing table storage and propagation of routing information are drastically reduced, the flooding issue in reactive approaches remains as the main challenge.

Many researchers believe that the problem of efficient operation over a wide range of conditions can only be addressed by a hybrid routing approach, where proactive and reactive behaviour is exploited to match different operational conditions. They argue that regardless of the preferred routing scheme, there will be some circumstances under which it will not perform desirably. A more promising approach for such protocol hybridization is to employ more than one protocol and have them operate in the network simultaneously, but with different scopes. For instance, ZRP [29], one of the leading hybrid routing protocol, divides the network into several zone in each of which an independent routing protocol may operate.

2.2 Ad Hoc On-Demand Distance Vector (AODV) Routing Protocol

The AODV routing protocol described in [27], builds on the DSDV algorithm briefly mentioned in the preceding subsection. The DSDV is a table-driven algorithm based on the traditional Bellman-Ford routing mechanism. In AODV nodes construct routes on an on-demand basis, while in DSDV terminals have to maintain a complete list of all existing routes.

The AODV routing protocol is a next-hop-based routing model where each host is supposed to keep a routing table that points to the next host to be used as the immediate relay to reach a desired destination. Moreover, a sequence number which is received from the destination and proving the freshness of the received information, is stored in the

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routing table. As in other reactive protocols, AODV comprises of a route discovery procedure as well as a route maintenance procedure. During the route discovery procedure, the source broadcasts a route request (RREQ) packet and floods the entire network. Then the node waits for a reply coming from the destination. If by a certain time, the route reply is not received, the source may retransmit the RREQ or may assume that the destination is unavailable. Furthermore, AODV uses destination sequence numbers to ensure that all routes in the network are both loop-free and up-to-date. Upon receiving an RREQ, nodes check if they have already seen the RREQ by observing both the broadcast ID and the source IP address. If so, the RREQ should be discarded. Otherwise it sets a reverse path pointing toward the source. The reverse path is indeed to be used by the destination when sending the route reply (RREP) packet back to the source node. In addition to the reverse path, AODV requires nodes along the negotiation path to set up the forward path, where data transmission will occur. Figure 4, illustrates the route discovery phase in a network where AODV is used.

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........➤ Represents transmission of RREQ

◄———— Represents links on reverse path (RREP)

⌒◄ Represents links on the forward path (Data)
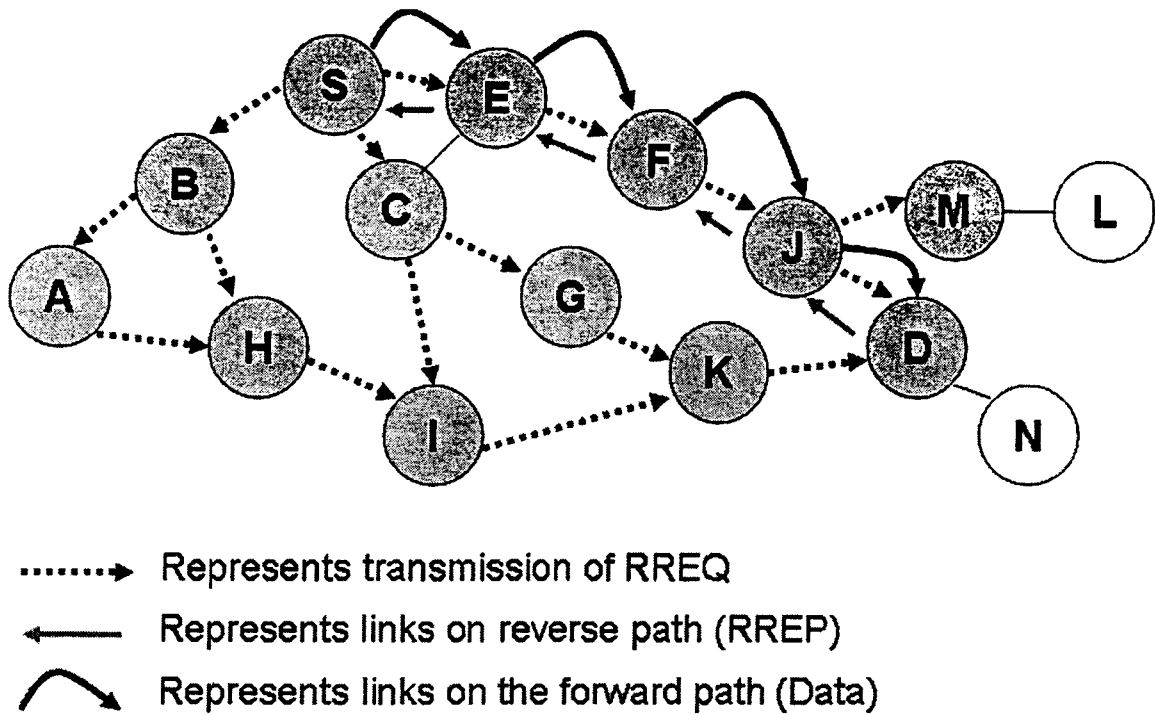
Figure 4.   RREQ propagation and path reverse setup in AODV

During the route maintenance phase, each node updates its routing table by receiving a

HELLO message periodically transmitted by its immediate (one-hop) neighbours.

Meanwhile if an error occurs on an active route, all upstream nodes along the broken link

are notified. One may now realize that HELLO messages play a vital role in AODV,

since without them, the route maintenance procedure would not achieve the desired

functionality.

2.3 Problem of Special Interest

As previously mentioned in this work, a straightforward implementation of route

discovery in reactive routing protocols is to employ a query propagation mechanism,

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where source node broadcasts a query packet throughout the entire network in order to discover a route to its desired destination. In spite of its simplicity, scarcity of some network resources in the wireless environment, particularly battery lifetime and wireless transmission capacity, has motivated many researchers to seek optimization to flooding-based approaches.

Redundancy, contention and collision are the main drawbacks of flooding [6]. Redundancy occurs when a node rebroadcasts a request message to its neighbours where that message has already been received. Moreover, upon re-broadcasting control messages, a node has to contend with the other nodes in the network to gain access to the wireless channel. Furthermore, there might be collisions of packets in the network if a collision avoidance mechanism is not employed.

In the following subsection we will be studying some of the proposed schemes to alleviate the flooding problem. Later, our proposed approach is described. Further elaboration of our methodology is discussed in the subsequent chapter.

2.4 Related Studies

In the last few years, different schemes and methodologies have been employed to address and resolve the flooding problem existed in wireless ad hoc reactive routing protocols. We can largely classify those approaches into one of the following categories: 1) probabilistic schemes, 2) location –based schemes, 3) cluster-based schemes and 4) hierarchical schemes.

In this subsection we review the literature related to above-mentioned schemes as well as the cross-layer design related studies.

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2.4.1 Flooding Problem Studies

The authors in [4], one of the earliest proposed probabilistic schemes, have briefly mentioned that an intuitive way to reduce broadcasts is to use probabilistic re-broadcasting. However they do not study problems introduced by this scheme in realistic ad hoc network topologies. The basic idea in such schemes is as follows: a node initiates a flood of route query packets in order to discover a route to its intended destination. All other nodes that receive the query packet will rebroadcast in order to forward it to their neighbours with some probability p and discard it with probability 1-p [3, 10]. In their work, Krishnamachari and Wicker have suggested that based on their experimental results, there is a critical value of forwarding probability, which is necessary to ensure all nodes receive the route query [3]. This threshold is referred to as "Phase transition threshold". They have shown that as the number of neighbours that each node has increases, the critical value decreases. Thus there is a trade-off in this situation: if the transmission range is large, more power is expended by each node, but the number of route query packets is minimized, while if the transmission radius is small, less power is expended, but the number of route query packets increases.

In another similar work, Sasson and Cavin investigated the phase transition phenomenon in a small IEEE 802.11 ad hoc network. They claim that they observed far fewer control messages than the previous works. However, in their setting a transmission can block many messages and therefore, a higher probability of broadcasting will result in a smaller propagation probability. Furthermore, their experiment emphasizes the fact that their relatively good results applies only to small networks [7].

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Later in 2002, Haas and Helpern exploited a gossip-based approach by using gossiping probability between 0.6 and 0.8. They claim that this amount suffices to ensure that almost in every execution; most of the nodes get the message. Their simulations show that adding gossiping to a reactive routing protocol (AODV in their experiment) in a large network results in up to 35% fewer control messages. For smaller network however, they do not achieve the same improvement.

In all probabilistic researches that we investigated, the following problem remains unresolved: how to settle the probability p at which a host should rebroadcast a message as p depends on many network parameters including topology, node density and the number of times that a node can hear rebroadcast messages that are not immediately available for the nodes [6].

Along with other four schemes, a location-based scheme has been proposed in [4] as an approach to alleviate the flooding problem. The authors have presented their method based on the assumption that location information of all broadcasting nodes are available. By using such information, additional areas that each broadcasting node covers can be calculated. To determine whether the receiving host should rebroadcast or not, this value will be compared to a predefined coverage threshold.

The authors in [11] have proposed a gossip-based ad hoc routing protocol using some location information. Their suggested protocol works under the assumption that the destination and the source location can be ascertained by means of a location service. This allows gossiping to be limited to nodes within the ellipse centered at the source and destination.

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Lim and Kim in [8] proposed two location-based models called "self pruning" and "dominant pruning". They showed constructing minimum cost multicast tree is hard since most algorithms require global network topology information that due to free node movement in ad hoc environment may not be feasible. In both of their offered schemes, the knowledge of directly connected neighbours is exploited but in dominant pruning, the range of neighbourhood information is extended into two-hop nodes. They have also concluded that while dominant pruning should perform better than self pruning because it is based on extended knowledge, its larger overhead may make it less desirable in highly-congested networks compared to self pruning [8].

Later in 2005, the authors of [9] have introduced a new hybrid method combining the counter-based method and the location-based method. The counter-based method is a variant of probability-based method. In addition to properties of probabilistic schemes, the counter-based approach takes the network dynamics into account particularly when a decision on the forwarding is being made. For this purpose, nodes have a timer for each message they receive. The delay time for each timer is randomly set when the node receives a message. The counter increase when the node overhears duplicate messages that are being forwarded by its neighbouring nodes. If the counter exceeds a certain threshold when the timer expires, then the node cancels forwarding. In the proposed hybrid model in [9] however, each node will make an independent decision on forwarding based on two criteria: location of the nodes and the density of the network. Although forwarding decision procedure is very similar to that of counter-based schemes, the delay time of each node will be adjusted based on the distance from the previous forwarder.

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The major drawback of location-based schemes is their requirement of systems like Global Positioning System (GPS) which itself requires additional hardware and protocols which may not be a cost effective solution.

It has been shown that cluster-based architecture guarantees basic performance achievement in wireless ad hoc environment with a large number of mobile nodes [13,17]. One benefit is in routing which is also related to our problem of interest. The set of cluster gateways and cluster heads can normally form a sort of backbone for inter-cluster routing and consequently the generation and spreading of routing-related information can be restricted in the set of these nodes [12, 15].

One of the earliest clustering algorithms called linked cluster architecture (LCA) was introduced by Baker and Ephremids in 1981. In their suggested work, each node is assigned an identification number and when a group of nodes reaches within transmission range of each other and starts forming a cluster, the terminal with the highest identification number receives the cluster head status. However, because of mobility, nodes in clusters may change. Therefore, new control messages are needed to select and form new clusters in the network. [6].

The authors in [16] proposed a clustering scheme called Least Cluster Change (LCC) which is considered to be a significant enhancement of lowest ID clustering (LIC). In LCC the clustering algorithm is separated into two stages: cluster formation and cluster maintenance. In the first step mobile nodes with the lowest ID in their neighbourhood are selected as cluster heads. But only under two cases re-clustering is invoked: 1) when two cluster heads move into the transmission range of each other and 2) when a mobile node does not have access to any cluster head. Although LCC

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significantly improves cluster stability by abandoning the requirement that a cluster head should always have some properties in its local area, the above-mentioned procedure shows that a single node's motion may still invoke the cluster structure re-computation, that if happens, the large overhead for clustering may not be avoidable.

In [18, 19], the authors have proposed two different non-overlapping cluster architecture. In [19], the authors have suggested an adaptive clustering scheme in which cluster architecture is formed without cluster heads. They have reasoned that because cluster heads always bear extra work compared with ordinary member nodes, their non-existence leads to remarkable enhancement of the control messages in the network [12].

All above-mentioned clustering approaches are referred to as conventional clustering scheme in which periodically advertising of cluster-dependent information to maintain the cluster structure, can not be avoided. In 2003, the authors of [20] proposed a clustering model called Passive Clustering (PC) that did not use dedicated clustering-specific control packets. In such models a node may possess one of the following four states: initial, cluster head, gateway or ordinary. Only nodes with "initial" status have the potential to become cluster heads. Moreover, the main assumption here is that all nodes have the state of "initial" at the beginning. When a node has something to send, it introduces itself as cluster head in the broadcasting packet. Nodes that hear just one cluster head become ordinary nodes and if any node receives from more than one cluster head, has to change its current state to "gateway" state. In PC, ordinary nodes are not allowed to rebroadcast flooding packets, and thus the replicated flooding traffic can be significantly reduced.

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Inspired by passive clustering, the authors in [21] suggested that node states can be restricted to only two states namely MN (Mobile Node) and FN (Forwarding Node). In their hierarchical approach, dynamic source routing (DSR) has been modified to match their methodology. Their results show that remarkable reduction in overhead messages and consequently improvement in delay and throughput compared with regular flooding can be expected.

2.4.2 Cross-Layer Design Studies

Cross-layer design is an active theme in wireless ad hoc network design. Recently many researchers have emphasized on the significance of cross-layer design in the overall wireless network optimization. In 2002, Goldsmith and Wicker studied design challenges of energy-constrained ad hoc wireless networks. They suggested that when energy is a constraint or the application has high bandwidth needs, the regular layered approach will not be a suitable model. They proposed an adaptive cross-layer protocol stack where at each of its layers, adaptivity should compensate for variations at that layer based on the timescale of those variations [22].

The authors in [24] have introduced a fairness concept for wireless systems that employs various cross-layer strategies and showed its advantages when compared to existing resource allocation mechanisms used in wired communications. Based on the order in which cross-layer optimization is performed, they have proposed the following classifications: 1) Top-down approach, which has been deployed in most of the existing systems. In such approach, the application layer prescribes the MAC parameters and strategies. 2) Bottom-up approach, where the lower layers try to prevent the higher layers

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from losses and bandwidth variations. 3) Application-centric approach, in which based on

the requirements, the application layer optimizes the lower layer parameters in a bottom-

up or top-down manner. 4) MAC-centric approach, where traffic information of the

application layer is passed down to the MAC. Then MAC determines which application

layer packets / flows, should be forwarded. 5) Integrated approach, in which strategies are

decided jointly.

In 2005, the authors of [6] investigated the effects of cross-layer elements in a

hierarchical wireless ad hoc protocol design. Their cross-layer design based approach

exploits MAC layer parameters in the proposed node selection mechanism. Their

simulation results show remarkable improvement in network throughput compared to the

one without cross-layer design.

Although in recent years numerous researches have been conducted in the area of cross-

layer design, however there have been few works in which one would find cross-layer

design as an approach to tackle flooding problem.

2.5 Our Approach

So far, we have made clear that our main objective in this work is to alleviate the

flooding problem that exists in the current wireless ad hoc reactive routing protocols. As

mentioned earlier in this work, passive clustering approaches have been regarded as

efficient techniques to reduce number of control messages in such routing protocols. In

this work, nodes have been classified into two categories, namely MN and FN. This

approach has been implemented in AODV, which after necessary modifications is

referred to as Modified Ad hoc On-demand Distance Vector (MAODV) Routing

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protocol. Later, placement of cross-layer elements in AODV has been attempted. More specifically, IEEE 802.11 MAC layer contention window (CW) has been employed to determine if the mobile nodes are eligible for re-broadcasting of control messages. Eventually we show that only combination of both methodologies can guarantee the best result. In other words when both cross-layer design elements and node categorization are exploited in AODV, simulation results indicate that significant enhancement in flooding compared to the current regular flooding approach can be expected.

Although in some researches [6] during the last few years, cross-layer design elements have been used to reduce the flooding effect, this work has a unique approach. The authors in [6] for example, have employed cross-layer design elements to optimize FN selection/deselection mechanism, whereas the presented work has sought to directly and dynamically affect the forwarding eligibility conditions of the mobile nodes.

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CHAPTER III

DESIGN AND METHODOLOGY

In this chapter we present our proposed modifications to AODV routing protocols to diminish the effect of flooding. We refer to our introduced scheme as Modified Ad Hoc On-Demand Distance Vector (MAODV) routing protocol. Then our proposed cross-layer design methodology is described. To further optimize our scheme, we discuss a routing algorithm in which both models are employed simultaneously.

3.1 Classification of Network Nodes

As previously mentioned, Passive Clustering (PC) proved to be a strong and effective scheme to alleviate the flooding issue. The authors of [20] assigned four different states to the nodes in the network. They are cluster-head, gateway, initial, and ordinary nodes. In contrast to their proposed model, in our work only two states have been considered: Mobile Node (MN), and Forwarding Node (FN). The basic idea here is to have flooding reduction as much as possible. We remember that during the path discovery phase of wireless ad hoc reactive routing protocols including AODV, a route query is broadcasted throughout the entire network. In other words every single node that receives such packets should rebroadcast it to its immediate neighbours. Flooding continues until the destination is found and then a route reply is transmitted back to the source. We refer to this approach as "blind flooding" which implies the fact that nodes in the network *blindly* rebroadcast all query packets. One may wonder how our classification of nodes can contribute to resolve this issue. Figure 5, illustrates a possible

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effect of our approach on flooding by comparing blind flooding with our introduced

classification scheme.
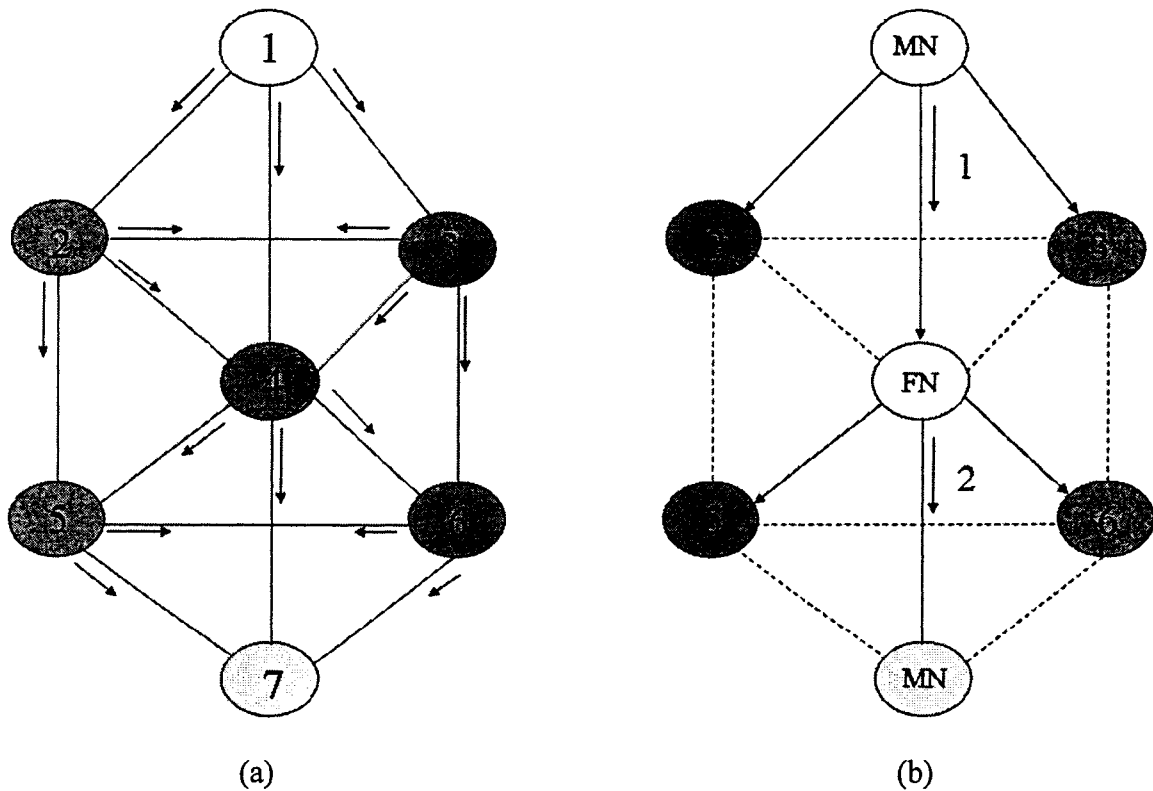
Figure 5.   Effects of node classification on flooding

In this scenario seven wireless nodes exist in the network. We assume that node 1 is a

data source and intends to negotiate with node 7. Thus node 7 is our desired destination.

Nodes 2, 3, and 4 are immediate neighbours of the source node. In Figure 5(a), when

neighbours receive the query packet which is intended for node 7, they all rebroadcast it

to their own neighbours. This process continues until the packet is received by node 7. In

contrast, nodes in Figure 5(b) do not blindly propagate request packets. In this scheme,

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nodes 1 and 7 have been assigned an MN state, while node 4 is the only Forwarding Node (FN) in the network. Since 4 is an immediate neighbour of 1, it is eligible to rebroadcast the query packet when received. Thus the rest of the network resources are not wasted by unnecessary packet propagations.

We can now summarize the functionalities of FN and MN nodes in the network as it follows:

Forwarding Node (FN):

1) Rebroadcasting Route Request (RREQ) Messages

2) Rebroadcasting Route Reply (RREP) messages

3) Forwarding data packet.

Mobile Nodes (MN):

1) Sending (source)

2) Receiving (destination)

Since we have chosen AODV as our intended protocol for corresponding modifications, RREQ is used to represent a query packet.

So far, we have made clear that the aim of classifying nodes in the network is to have minimum number of eligible nodes, which are able to rebroadcast query packets. As stated earlier in this work, to demonstrate our proposed scheme and prove its advantages over "blind flooding", we modify AODV, a well known reactive ad hoc routing protocol, so that our hierarchical approach can be employed. In the following subsection, more details on the modified protocol have been provided.

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3.2 Modified Ad-Hoc on-Demand Distance Vector (MAODV) Routing Protocol

To better understand our proposed modifications, one may need to have some knowledge on AODV structure. As we mentioned at early stage of this work, AODV does not require nodes in the network to maintain a list of routes to all possible destination. Like other reactive routing protocols, AODV operates on an on-demand basis. We modify AODV to fulfil our goal of node classification in the network. To choose forwarding nodes in the network, a random selection mechanism is used. Clearly number of forwarding nodes in the network should be reasonable, since by having too many of them we may not reach a desirable optimization level. Also, if there are few FN in the network, many route request destinations may become unreachable. This may happen due to lack of connectivity between forwarding nodes, because only FNs are eligible to rebroadcast overhead messages. We define an overhead message in this work as a message that is used in path discovery or path maintenance procedure. This includes both route request (RREQ), and route reply (RREP) message as well as route error (RERR) message.

When a node in the network receives a packet, the packet type has to be determined. If the received packet is not an AODV message, then the packet is delivered to the corresponding function. Otherwise the AODV Receive function has to deal with the received packet. Figure 6. shows the algorithm flowchart of our proposed model. Our algorithm starts after we realize that the received packet is an AODV message. As we remember, there are several routing messages in AODV. Thus at this stage we need to determine the type of the received AODV packet. Firstly, we observe the packet to see if it is a route request message. Upon noticing such message in regular AODV, the request

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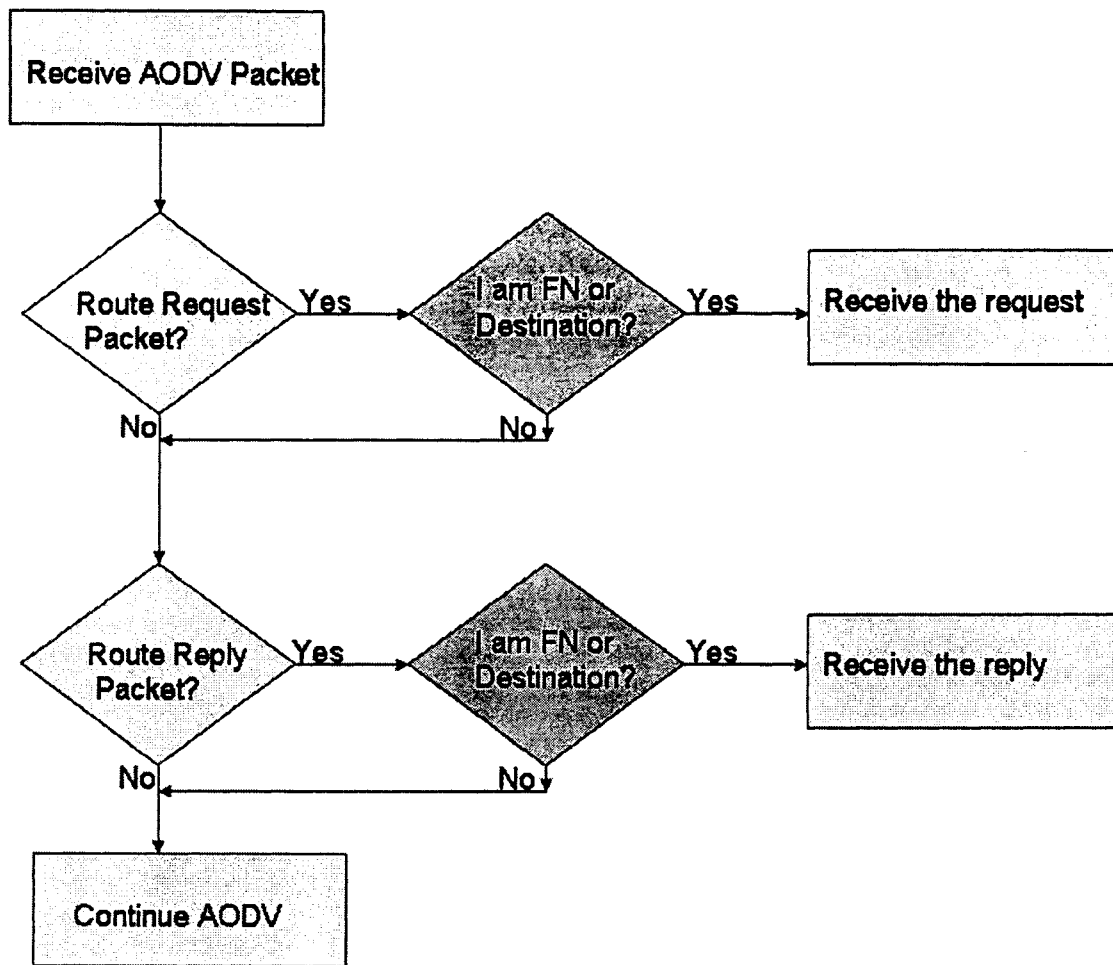
Figure 6. MAODV algorithm flowchart

packet would be received and rebroadcasted automatically. In contrast, our algorithm

ensures the eligibility of the node for forwarding the request. In other words, only if the

node has been assigned FN state, the route request message can be forwarded to the

neighbours. Otherwise the message should be discarded. Obviously, if the node is the

intended destination, no matter what the node state is, the packet has to be received.

Secondly, we examine the received message to see if it is a route reply message. Again,

the same condition should be satisfied in order to have the node forward such a message.

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It is shown in the flowchart that if the received AODV message is neither route request message nor route reply message, we will continue the normal AODV procedure.

3.3 Cross-Layer Optimization of AODV

Earlier in this chapter we mentioned that two methods have been used in our work to tackle the flooding problem in the network. In this subsection, flooding optimization of AODV from a cross-layer design point of view is discussed. First, the medium access method in the IEEE 802.11 is described. Later we explain how Contention Window (CW) of IEEE 802.11 is used in our algorithm to affect routing decisions of the network layer and optimize the performance of the network.

3.3.1 Wireless Medium Access Method in IEEE 802.11

The Distributed Coordination Function (DCF) is the fundamental access method in IEEE 802.11 used to support asynchronous data transfer. It operates solely in the ad hoc network. The DCF specifies the use of the CSMA protocol with collision avoidance capability.

Wireless networks use the CSMA protocol as their access mechanism to the channel. It is similar to the CSMA scheme used in wired LANs. However, the Collision Detection (CD) technique which is used in wired LANs can not be used in wireless environment. Instead, Collision Avoidance (CA) techniques are commonly employed in wireless networks to reduce the number of over-the-air collisions. In the CSMA/CA medium access, we can minimize collisions by using request-to-send (RTS), and clear-to-send (CTS) transmission frames. A Wireless node can establish communication by sending an

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RTS frame. The RTS frame includes the destination as well as message duration. The message duration is called the Network Allocation Vector (NAV). All other nodes will then back off the medium for the duration of the NAV [26, 32].

When DCF access method is employed, before a node starts a transmission, it senses the medium to ensure availability of the channel. If the medium is not found to be busy for an interval of distributed interframe space (DIFS), the node can continue with its transmission. The transmitted packet includes the projected duration of the transmission (NAV). Therefore, NAV information indicates how long the channel will remain busy.

As shown in Figure 7, In a CSMA/CA scheme, a random back off delay feature is provided before a node can attempt a new transmission. In the other words, when a node with a packet ready for transmission, finds the channel to be busy, it defers access to the channel until the end of the ongoing transmission. Upon finding the channel to be free, the node starts a counter called the back off timer by choosing a back off interval. The back off time is uniformly selected in [0, CW-1], where CW is defined as a contention window (back off window). Thus, the back off time is given by:

$$T = (R*CW)*Ts \qquad (1)$$

, where Ts is the slot time, R is a uniformly distributed random variable between [0, 1], and CW is the contention window. At first transmission attempt, the value of CW is set to CWmin. Until CW reaches its maximum value, at each unsuccessful retransmission attempt, its value is doubled [6, 26].

We can conclude from the above-mentioned mechanism that CW indicates how the surrounding channel is congested. This is the basis of our proposed algorithm for the cross-layer optimization of AODV.
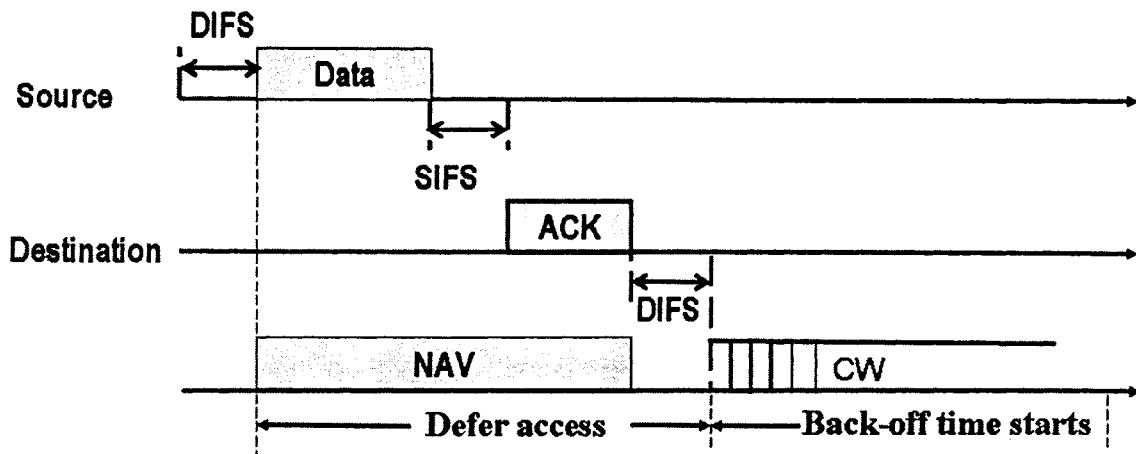
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Figure 7.   IEEE 802.11 DCF access method

3.3.2 Cross-Layered AODV Using Contention Window

We defined the contention window (back off window) in the preceding

subsection. It is understood from the described IEEE 802.11 access method that the

contention window can to some extent reflect the level of congestion in the surrounding

area of a network node. We also remember that our goal in this work is to counter the

flooding problem existed in the reactive routing protocols including AODV. There

remains an important question to be answered: How the contention window can be

employed to reduce the flooding in the network and consequently optimize the

performance of the network? We try to explain how our suggested approach answers this

question.

We define a contention window threshold at which the packet forwarding eligibility of

nodes in the network is determined. Our simulation results which are presented in the

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following chapter suggest that by assigning the threshold in a certain range, a higher
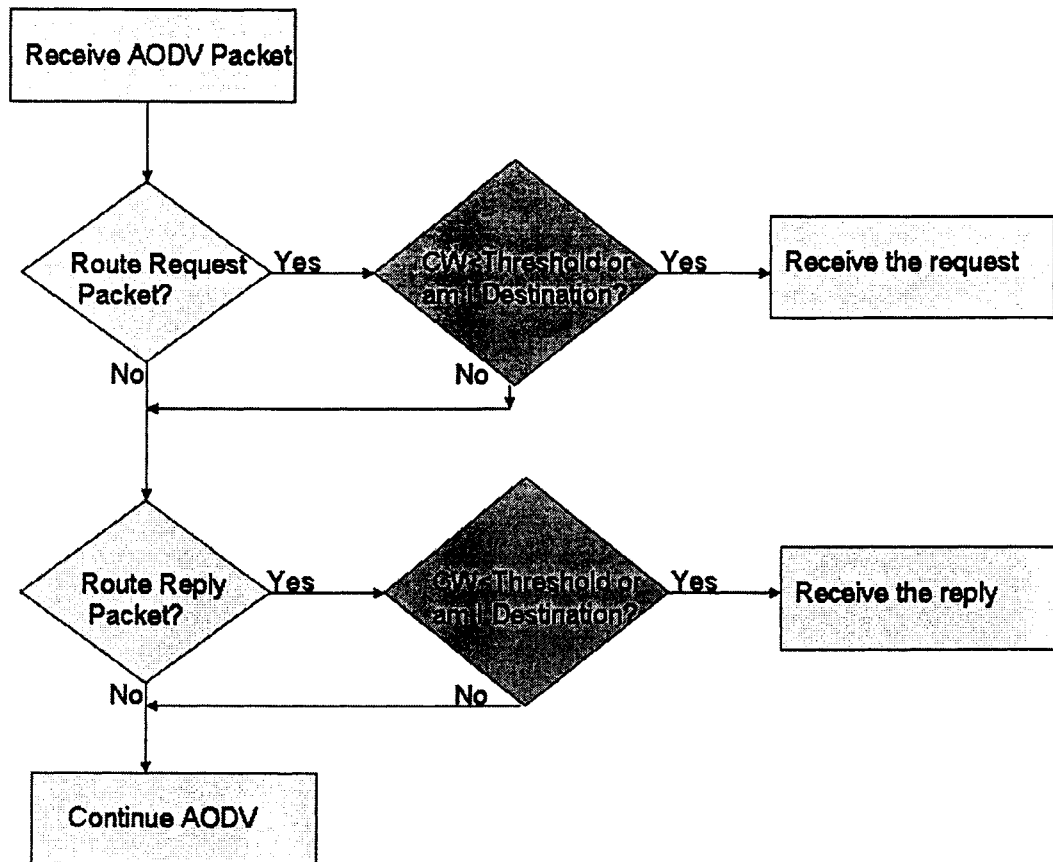
network performance can be expected.

Figure 8.   Proposed algorithm flowchart for cross-layered AODV

Again, the flowchart of our proposed algorithm is shown in the Figure 8. The main

difference in this algorithm compared to the MAODV algorithm comes from the

forwarding eligibility conditions. In contrast to MAODV, where only FN nodes are

eligible for the packet forwarding in the network, the later scheme is a dynamic approach.

Depending on the congestion level of its surrounding channel, any node in the network

may become eligible for further broadcasting. First, Like MAODV algorithm we observe

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whether the received packet is a route request message. If so, node's eligibility should be investigated. The node needs a contention window of smaller than the threshold. If this condition exists, the request message is received and forwarded to the neighbours. The rest of the scheme is similar to the MAODV approach which was presented in the previous section.

One may now understand how in our approach further propagation of packets to already congested areas is avoided. Moreover, the cross-layered AODV is a dynamic approach, because if a node has the contention window of smaller than the threshold, it can be used as a relaying node in the network, while in MAODV, assignment of forwarding nodes are done randomly.

3.4 Cross-Layered MAODV: A Combination of Two Approaches

The main philosophy behind developing this model is to take advantage of both proposed approaches simultaneously. Previously in our work, the cross-layer design approach was applied to AODV in order to alleviate the flooding problem in that routing protocol. Our combinational scheme instead, tries to optimize the Modified On-Demand Distance Vector (MAODV) routing protocol. In Figure 9, the corresponding flowchart is presented. In this scheme, two conditions must be satisfied before a node becomes eligible for packet forwarding in the network. In the other words in order to remain a potential forwarding node in the network, a node must have the FN state and at the same time its contention window must be less than the assigned threshold. If both conditions are satisfied, the received control messages (RREQ and RREP) can be accepted and rebroadcasted to the neighbours. Our simulation results also prove that the combinational

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scheme further enhances performance of the network even when compared to both

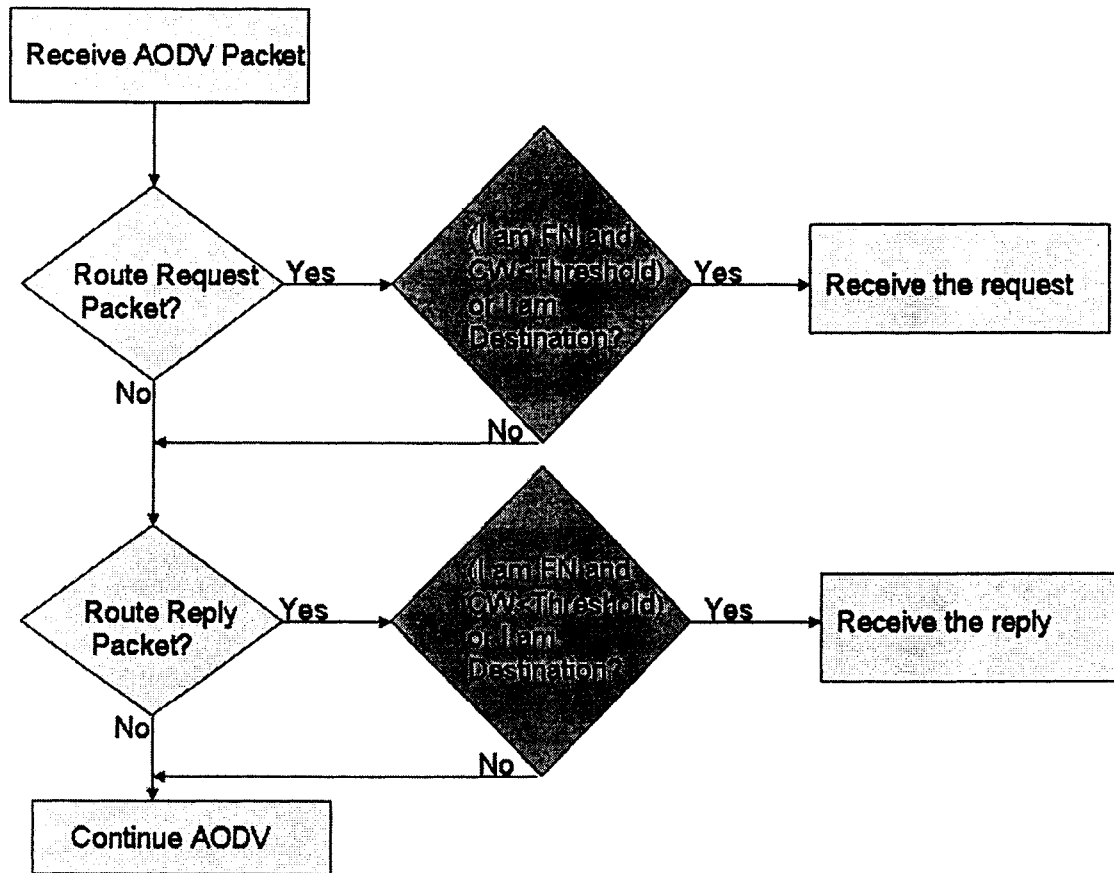MAODV and cross-layered AODV.

Figure 9.　　Proposed algorithm flowchart for cross-layered MAODV

In this chapter, basics of the both proposed approaches to tackle the problem of flooding

in the AODV routing protocol were explained. Algorithm flowcharts were also described

for the better understanding of the proposed modifications. Finally a combinational

scheme was introduced employing both cross-layer design and node categorization

methods. In the following chapter all above-mentioned schemes are simulated using NS-

2. Their performances are then analyzed.

CHAPTER IV

ANALYSIS OF RESULTS

In this chapter our simulation results along with our analysis of the results are presented. For our simulations, we used Network Simulator 2 (NS-2) [13] to implement and examine the performance of the proposed protocols. The effective transmission range of wireless radio in NS-2 is 250 meters and Wireless nodes were static during the simulations. Also, medium access control method is based on IEEE 802.11 with the capacity of 2 Megabits per second. Moreover, the following performance metrics have been investigated to compare the performance of the introduced routing schemes and the AODV routing protocol:

1. Normalized overhead: is measured as the ratio of the number of control messages (Overhead packets) to the number of successfully received data packets at destination.

2. Average delay per packet: is defined as the average end-to-end delay (in seconds) for the successfully received packets.

3. Packet Delivery Ratio (PDR): is defined as the ratio of the successfully received packets to the all transmitted packets by CBR sources in the network.

As shown in Figures throughout this chapter, our results are always compared with the regular AODV routing protocol. After presenting simulation results of our schemes

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separately, for a more clear comparison, they are shown together at the end of this chapter.

4.1 MAODV: Simulation Results and their Analysis

MAODV routing protocol is simulated with varied packet rates and different number of nodes in the network. Nodes are randomly distributed over a flat area according to uniform distribution function. Node densities are kept constant in the network when we increase the number of nodes to investigate the scalability of the routing protocols. For instance, the area is 800 meter by 800 meter when there are 75 nodes, and it is 1132 m by 1132 m when there are 150 nodes in the network. All traffic sources are CBR (Constant Bit Rate) with 512 bytes per each packet. We also change the packet generation rate in order to examine the network performance under different traffic loads. Each CBR source starts generating packets randomly during the first 20 seconds of the simulation, where each simulation runs for 200 seconds. In order to ensure the reliability of our results, each scenario is simulated 10 times with a randomly chosen network topology. We only report average of the produced results. As we remember from previous chapter, nodes in MAODV are classified as MN and FN. Also, we remember that FNs are selected randomly from the wireless nodes in the network. MNs are allowed to perform routing functions only if they are either source or destination. In every simulation, 35% of the nodes in the network are assumed source or destination.

As we previously stated, the main drawback of AODV like any other on-demand based routing protocol is employment of flooding in its route discovery procedure. This leads to generation of large number of overhead packets. Figure 10 clearly demonstrates how our

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proposed modifications reduce the effect of flooding in the network. In this scenario, 26% of the nodes are assigned as FN. As we can notice, MAODV significantly reduces the routing overhead if the number of nodes increases in the network. This behavior reflects our expectations, because only 26% of the nodes are allowed to rebroadcast overhead messages. As the number of nodes in the network increases, naturally more communications occur and consequently more overhead packets are generated. As is shown in figure 10, when there are a low number of nodes in the network, the overhead difference between AODV and MAODV is negligible, because only a few nodes are in communication. But when we increase the number of nodes, AODV routing overhead sharply increases, whereas overhead increase in MAODV is not considerable. For example, overhead of AODV is 9 times more than MAODV at 75 nodes, and 15
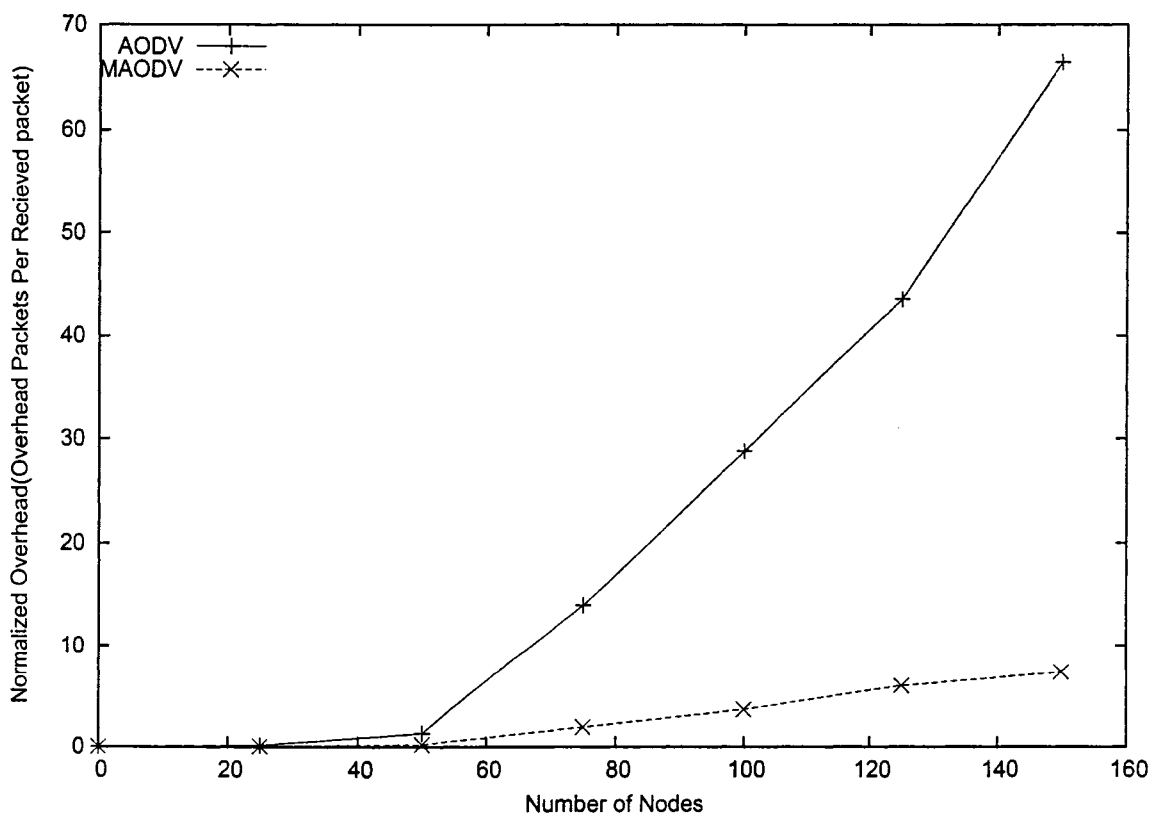

Figure 10. MAODV: Normalized overhead vs. number of network nodes

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times more at 100 nodes. Since routing overhead in AODV becomes significantly larger and consequently more congestion occurs when the number of nodes increase, the time for a packet to travel from the source to the destination becomes longer. This delay is another important metric when performance of the network is under investigation.
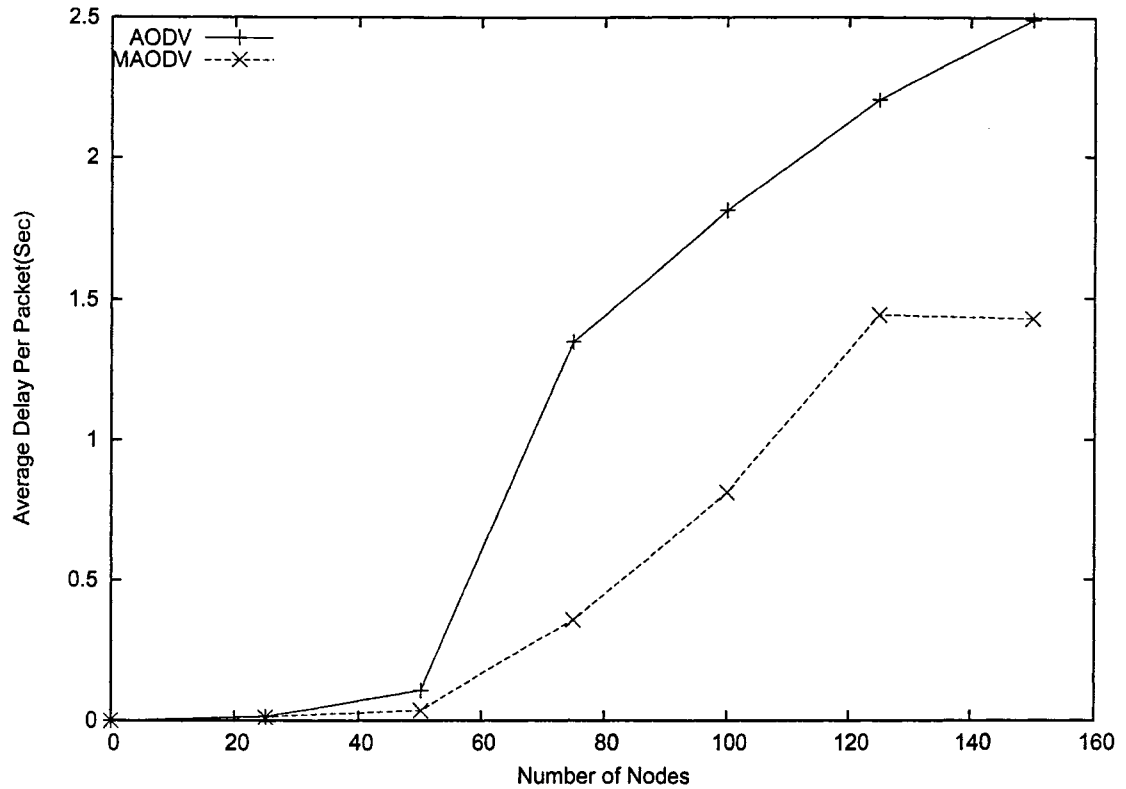

Figure 11. MAODV: Average delay vs. number of network nodes

Figure 11, confirms our explanation. It again shows as the number of nodes increases, MAODV gives better delay performance compared to AODV.

Another important metric that is affected from large routing overhead in the network is packet delivery ratio, which represents ratio of the successfully received packets to the generated CBR packets. It is exhibited in Figure 12 that AODV packet delivery ratio is slightly better than MAODV when there are not too many nodes in the network. That is

again due to the negligible routing overhead difference between the two compared protocols when few communications happen in the network. But by increasing the number of nodes, one can easily notice how MAODV shows the better performance. If the assigned number of FNs in the network is too low, we may face many unsuccessful packet transmissions. Since FNs are the only eligible relaying nodes in the network, many packets may not be able to find an intermediate node to reach the destination if FNs are not assigned adequately. Therefore, we can state that there is always a tradeoff between number of FNs and packet delivery ratio in MAODV. Our many simulations suggest that best result can be expected when approximately 25 % to 29% of network nodes are assigned as FN.
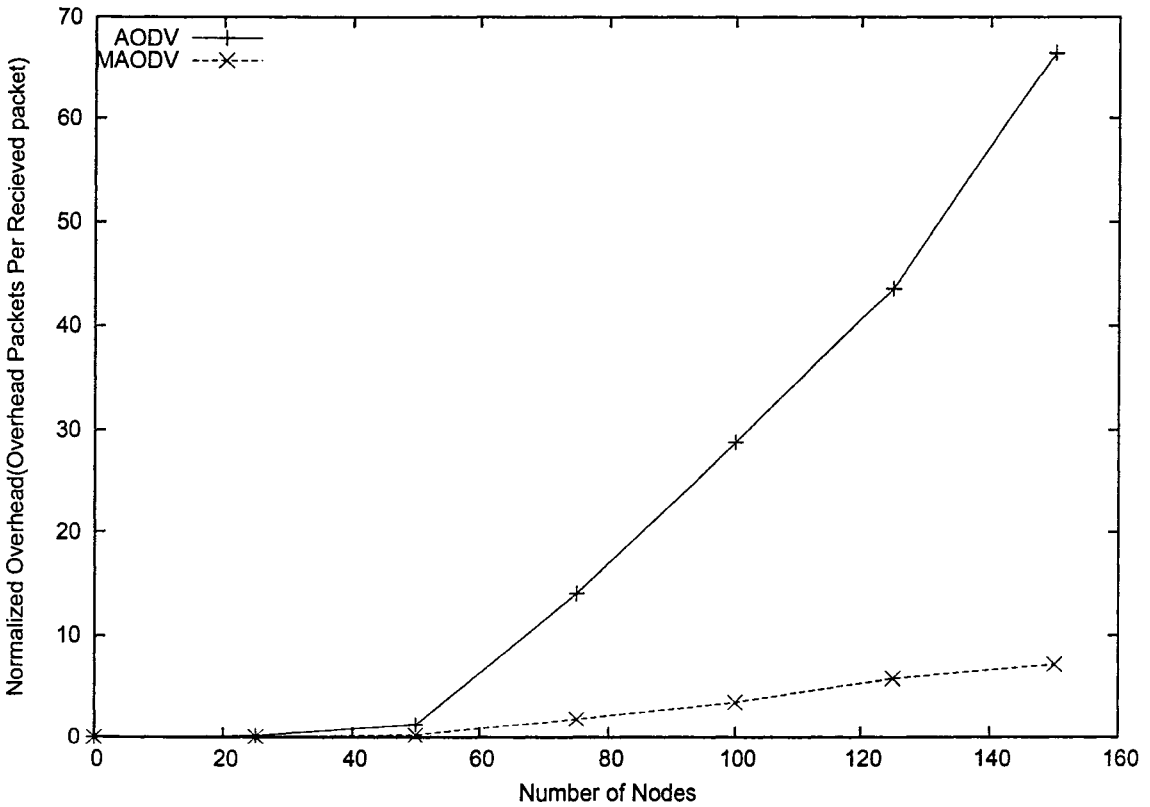

Figure 12. MAODV: Packet delivery ratio vs. number of network nodes

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So far, we have presented our results based on the constant traffic load in the network. To better evaluate our proposed scheme, we decided to test some of the network performance metrics under differing traffic load. Figures 13 and 14 show normalized overhead and packet delivery ratio performance of the network respectively.
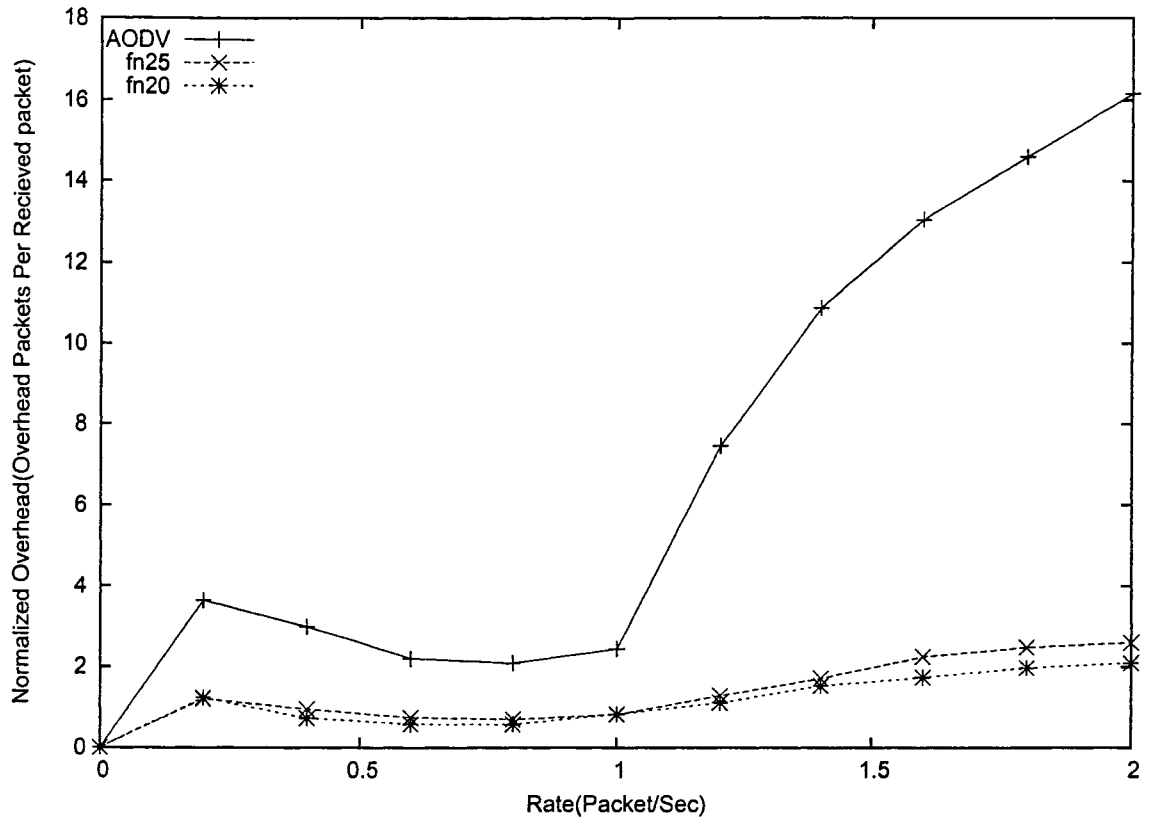

Figure 13. MAODV: Normalized overhead vs. data packet generation rate

In Figure 13, normalized overhead of AODV is shown compared to normalized overhead of MAODV with 20 and 25 FN nodes. It can be understood from the figure that if the network is loaded with more than 1 packet per second, normalized overhead of AODV steeply increases as higher data traffic is generated. Also, we can notice that MAODV with 20 FNs has the least overhead; because the later has fewer eligible nodes to rebroadcast control messages and consequently impose less overhead on the network.

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One may wonder how data traffic may affect routing overhead when overhead messages are propagated only during the route discovery procedure. Although we may not see any direct relationship between data traffic rates and routing overhead, there are some facts that suggest such relationship exists. We should note that high data traffic rates cause more congestion in the network. In such circumstances, when a node needs to find a route to its desired destination, it may fail to finish the route discovery procedure several times. Consequently more and more overhead messages are generated before a route toward the destination is discovered.
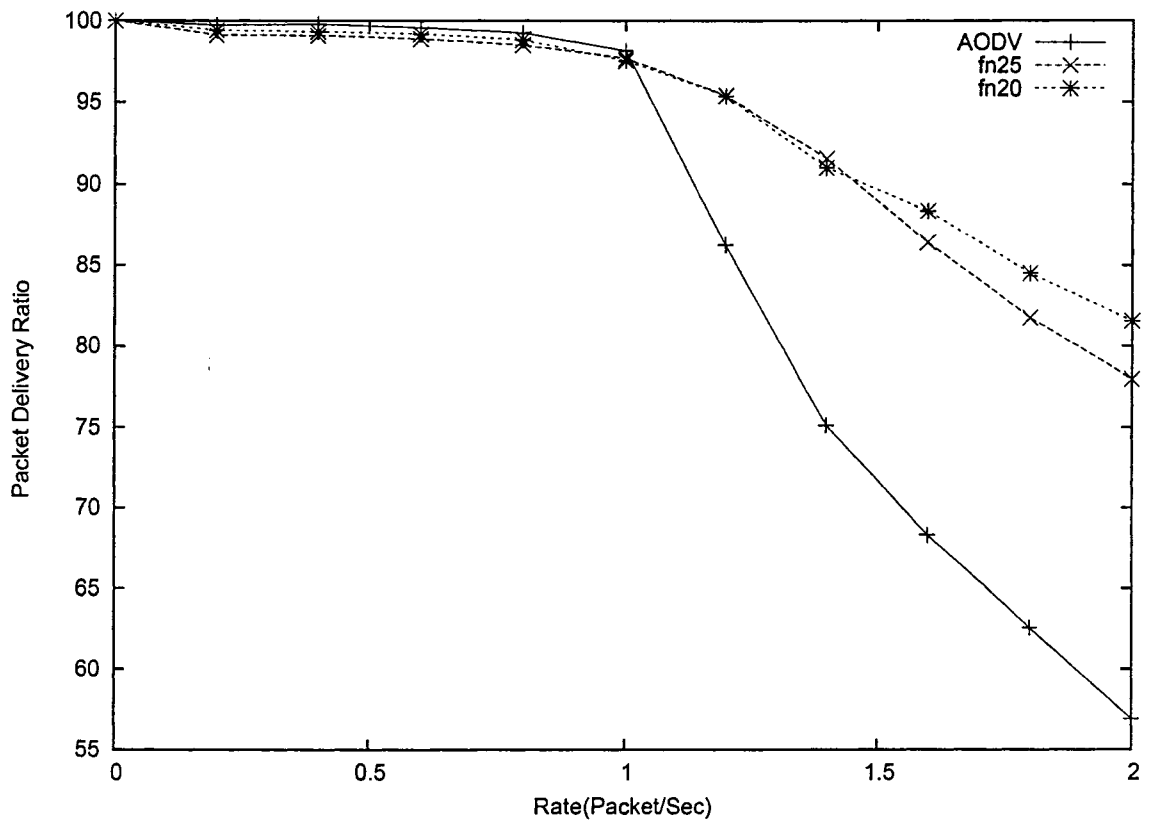

Figure 14. MAODV: Packet delivery ratio vs. data packet generation rate

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Under the same condition, we measured performance of the packet delivery ratio as shown in Figure 14. AODV performs slightly better than MAODV when data rate is less than one packet per second. When the traffic load becomes more than one packet per second, packet delivery ratio of our proposed scheme performs better than packet delivery ratio of AODV. Again this is justified, because AODV generates significantly more overhead messages than MAODV. Thus, higher congestion in AODV is expected when compared to MAODV. Naturally, we expect a better packet delivery ratio in a network with less congestion.

4.2 Cross-Layered AODV: Simulation Results and their Analysis

As in the MAODV case, Cross-Layered AODV (CLAODV) is simulated with varied packet rates and different number of nodes in the network. The simulation parameters used in CLAODV simulations are the same as those used in MAODV simulations, unless otherwise stated.

As we remember from the previous chapter, we came to the conclusion that the contention window (CW) can reflect the congestion level surrounding a given area. In our proposed scheme, we suggested using a threshold to determine forwarding eligibility of the wireless nodes in the network. NS-2 assigns 32 as the minimum value for the contention window (CWmin). We assigned 64 to our threshold in all presented simulations in this subsection. In other words, a node can act as a relaying node and forward the received packets if the current value of its contention window is smaller than 64. Therefore, if a node had to back off the channel more than once in its most recent transmission, it is not allowed to rebroadcast the received query packet. Figure 15, shows

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our simulation results for different number of nodes in the network, where normalized overhead is measured.
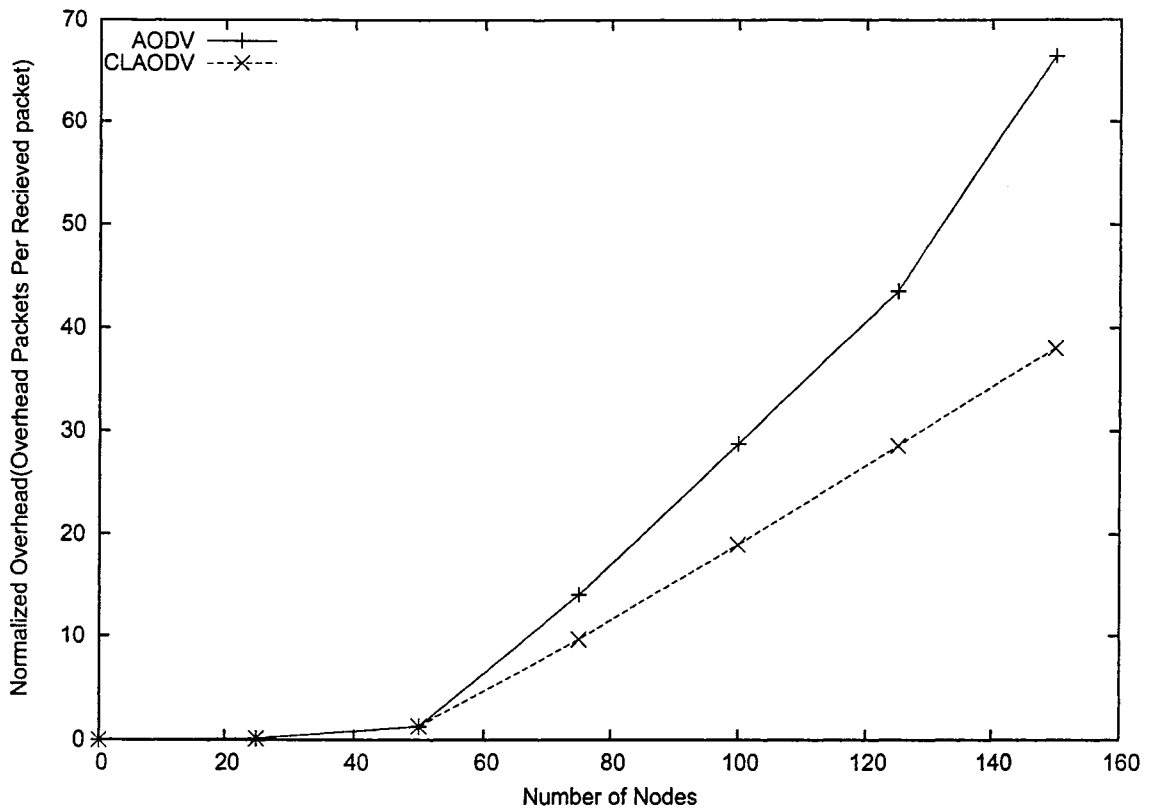

Figure 15. CLAODV: Normalized overhead vs. number of network nodes

When the number of nodes in the network increases, both protocols produce larger overheads as expected, but CLAODV outperforms AODV in terms of the normalized overhead. Since we have limited number of forwarding nodes in the network by imposing a maximum acceptable value for the contention window, less overhead in CLAODV is generated compared to AODV. We also measured the delay performance of CLAODV and then compared the results with the delay performance of AODV as is shown in

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Figure 16. Delay results suggest that when there is high number of nodes in the network, AODV slightly performs better than our proposed scheme, although performance remains the same for lower node numbers.
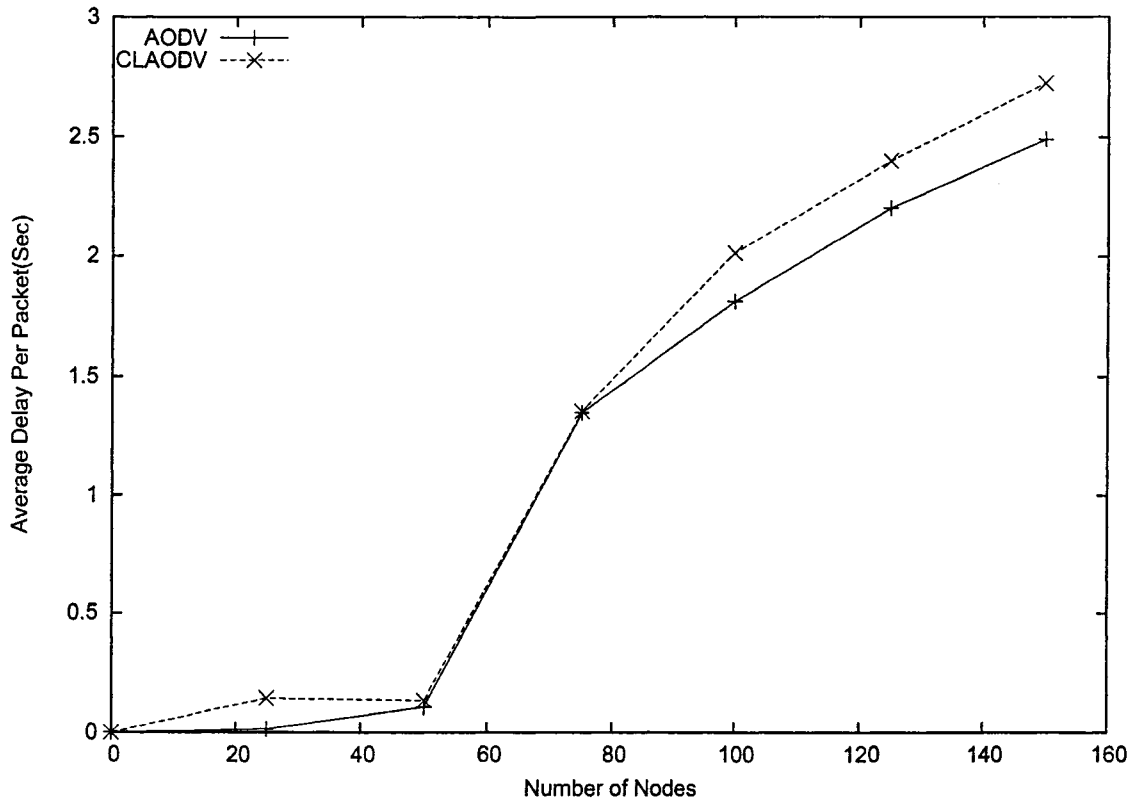

Figure 16. CLAODV: Average delay per packet vs. number of network nodes

To explain this behavior, we need to remember that in our proposed scheme, nodes in highly congested areas have a slim chance to become an eligible packet forwarder. Also, we now that when number of nodes in the network increases, routing overhead and consequently congestion increases in the network. Therefore, due to high congestion in the network, a source node may need to attempt several times before finding enough relaying node along the path toward destination. Naturally this situation causes longer delays for the transmitted packets.

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Finally, we simulated CLAODV under differing traffic loads to better evaluate our scheme. Figure 17, shows how packet delivery ratio performance of CLAODV is affected under different data traffic rates. Again it is compared to AODV packet delivery performance.
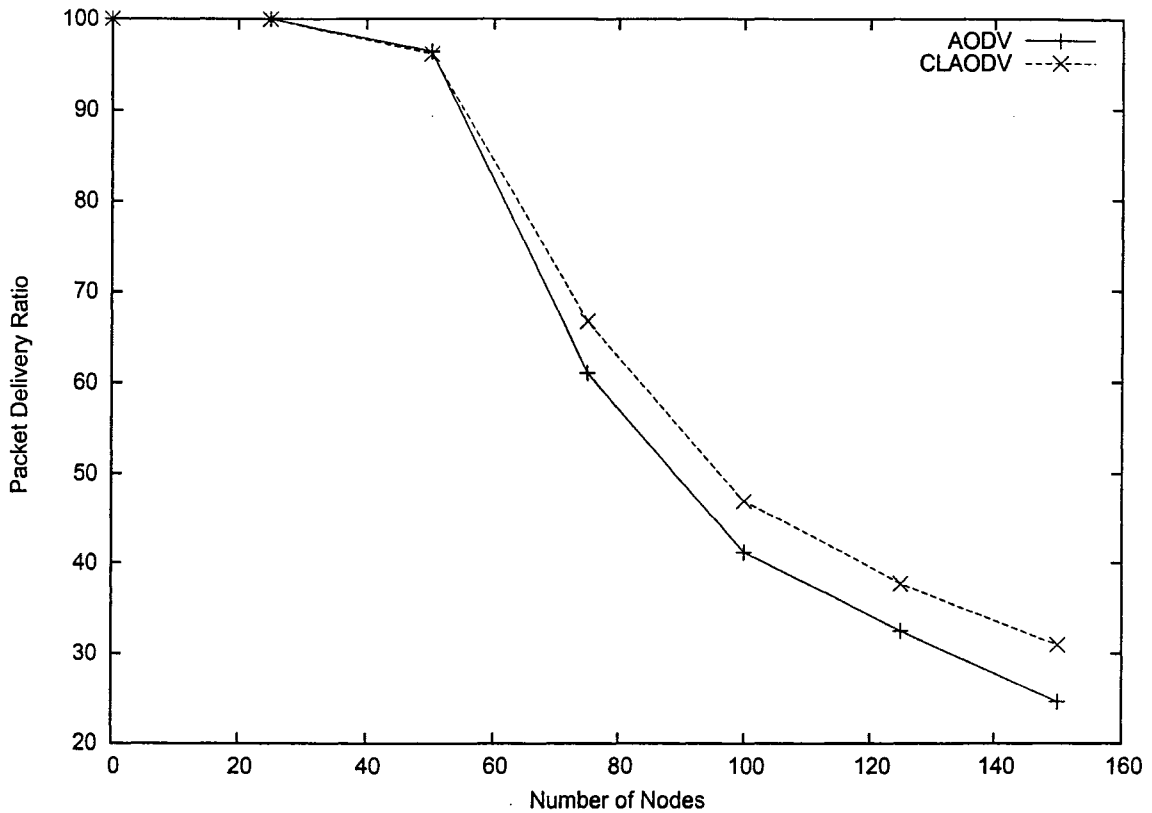

Figure 17. CLAODV: Packet delivery ratio vs. data packet generation rate

When the network comes under high traffic load (higher than 1 packet per second), the packet delivery ratio of CLAODV performs better compared to AODV. Packet delivery performance of our scheme performs slightly better, because we avoid routing packets in highly congested areas. This is very important, because in those areas, the potential risk of packet loss is much higher than other areas of the network.

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4.3 Combinational Scheme: Simulation Results and Comparison with Both Schemes

We mentioned in the preceding chapter that the main philosophy behind combinational scheme is to take advantage of both schemes simultaneously. Our simulation results simply satisfied our expectations in the sense that in every simulated scenario, this combinational scheme, which we refer to as Cross-Layered MAODV (CLMAODV), showed better performance compared to MAODV, CLAODV, and obviously AODV. The simulation parameters are the same as mentioned above for previous schemes. Since our explanations for both MAODV and CLAODV results are given in the previous subsections and they can be applied to this combinational approach, we do not intend to repeat them here again. For example, Figures 18 and 19 compare delay performance and packet delivery ratio performance of AODV, MAODV with 20 FNs and CLMAODV with 20 FNs under differing traffic load. However, It is shown how
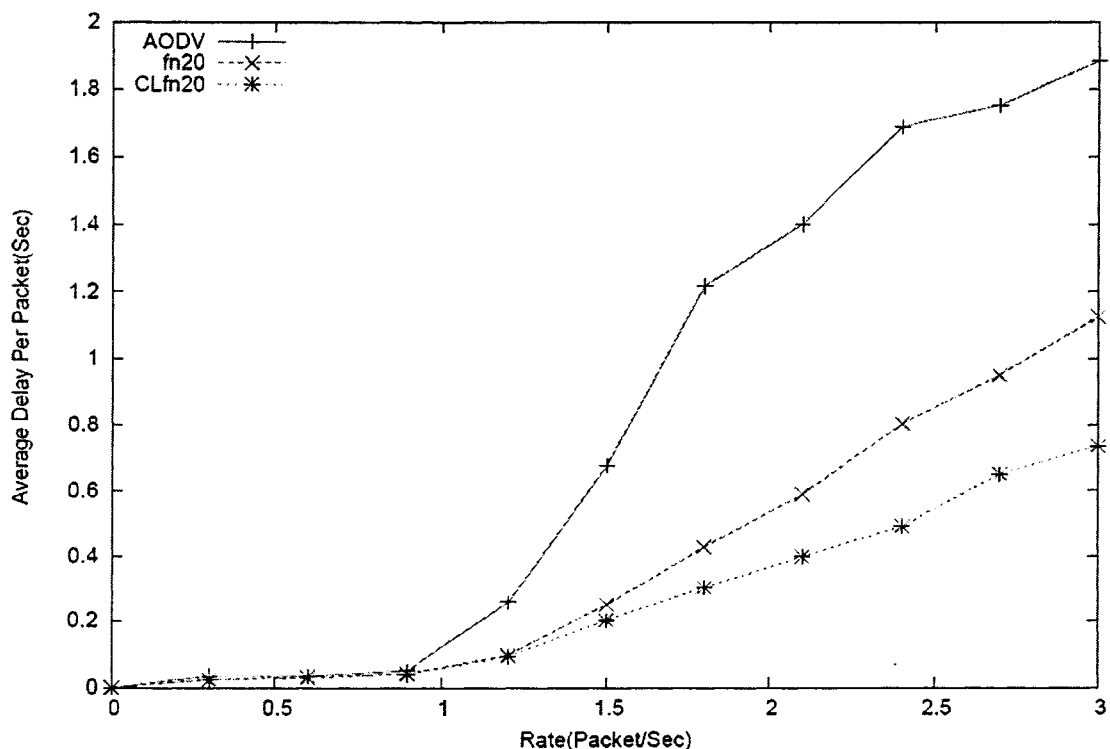

Figure 18. CLMAODV: Average delay per packet vs. data packet generation rate

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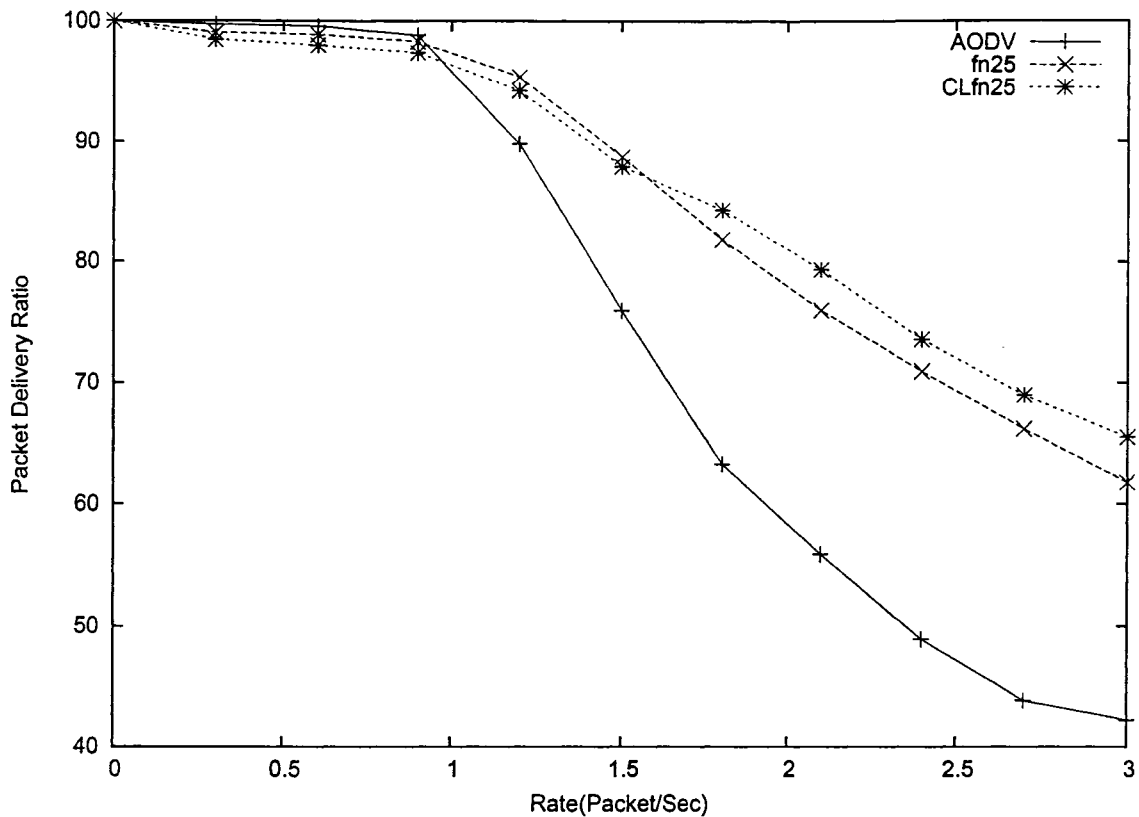
Figure 19. CLMAODV: Packet delivery ratio vs. data packet generation rate

CLMAODV produces the best results.

In addition to simulations whose results are presented above, many more simulations were done for all proposed schemes. Figures 20 to 22 compare all proposed schemes together with AODV to show better comparison. It is necessary to mention that in all following simulations, 26% of the nodes are assigned as FN and also we always assume that 35% of the nodes in the network are either source or destination.

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Figure 20. Total comparison: Normalized overhead vs. number of network nodes
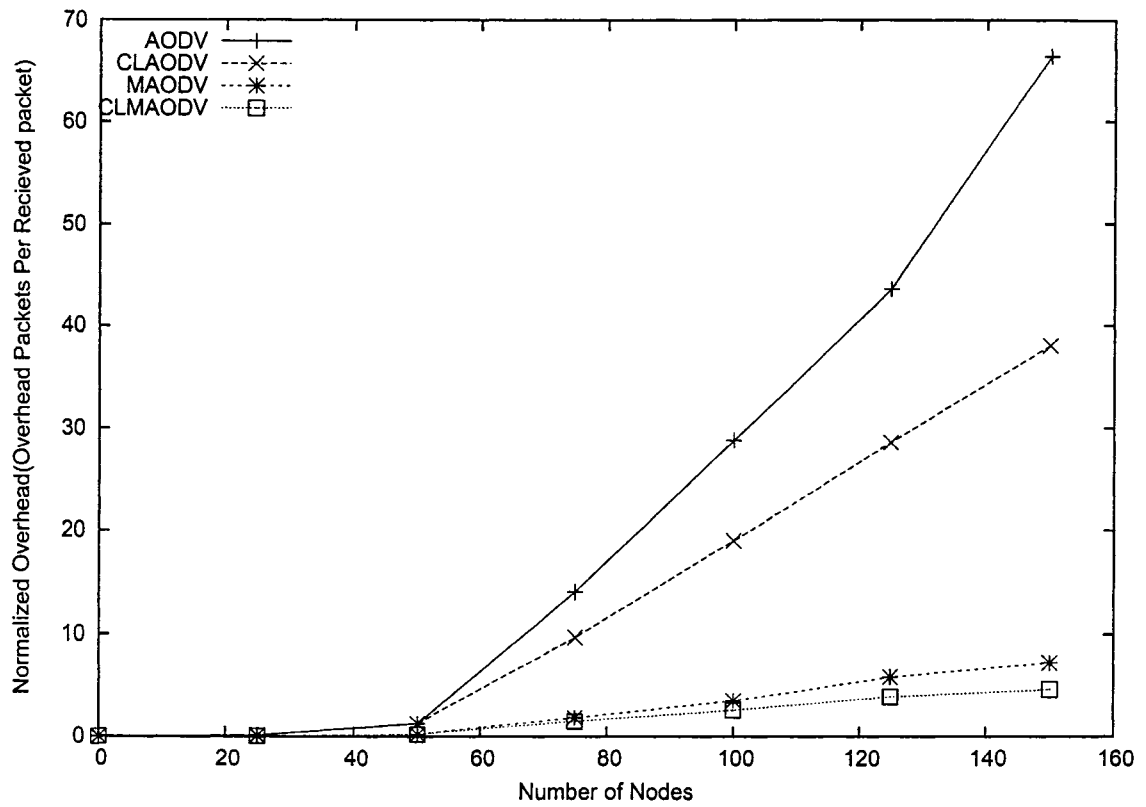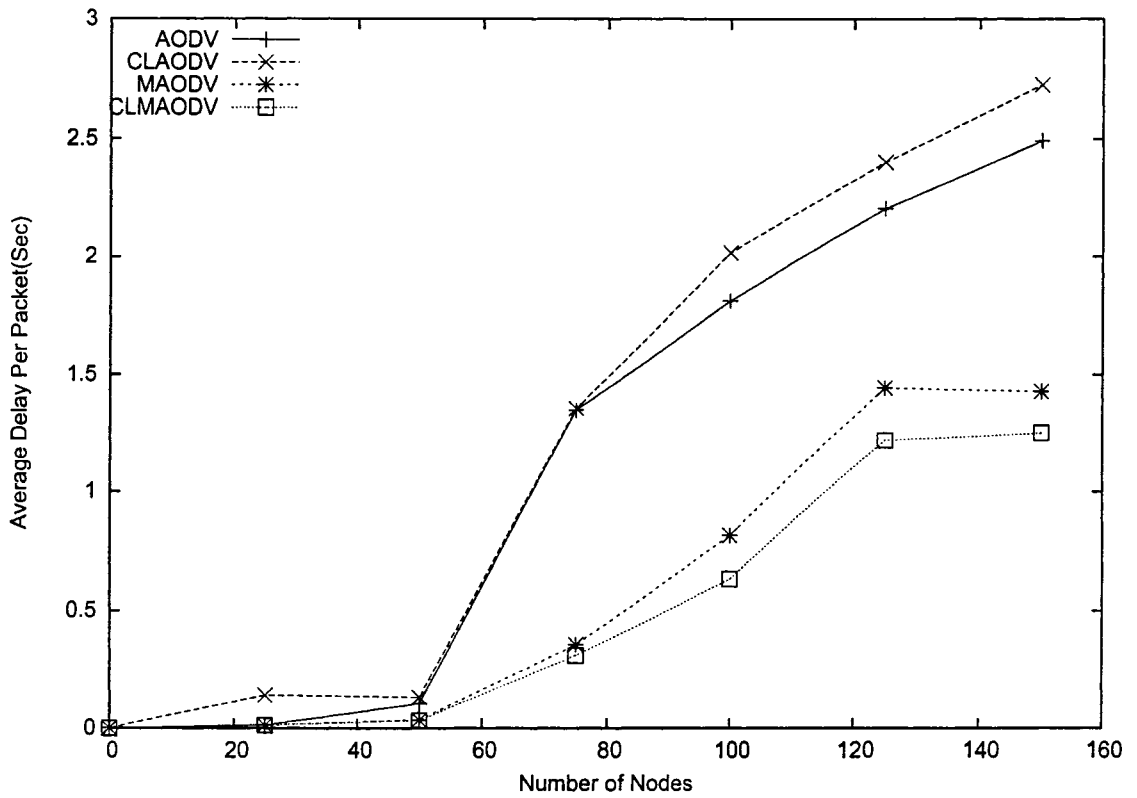
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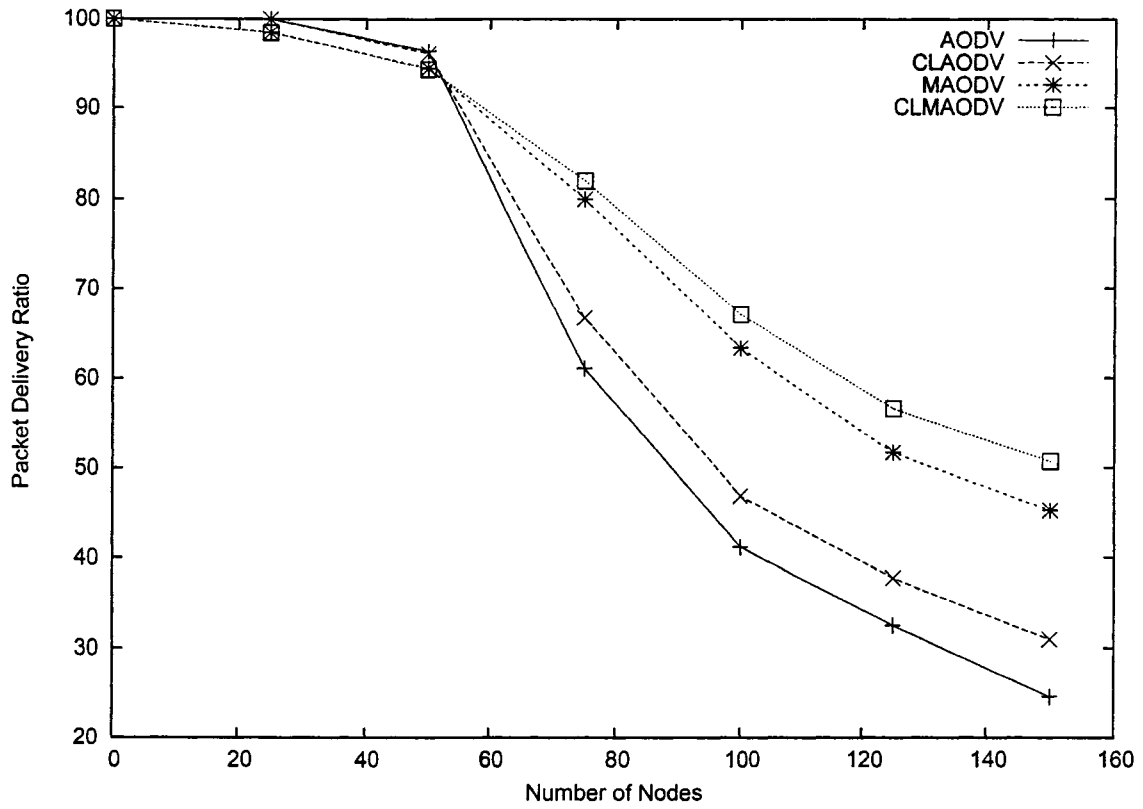Figure 21. Total comparison: Average delay vs. number of network nodes

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Figure 22. Total comparison: Packet delivery ratio vs. number of network node

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In this chapter we investigated the network performance of our proposed protocols via computer simulations. Our simulation results confirmed the validity of the proposed modifications to reduce flooding in the network. First, we investigated performance of the proposed MAODV routing protocol. Our results showed significant improvement in the following performance metrics compared to performance of AODV: 1) normalized overhead, 2) average delay per packet, and 3) packet delivery ratio

Moreover, we investigated the above-mentioned performance metrics for CLAODV. Again, compared to AODV, our results demonstrated a considerable improvement in both normalized overhead and packet delivery ratio. Only delay performance slightly declines.

Finally, we showed our combinational approach –CLMAODV- gives the best performance when the same performance metrics investigated. A more comprehensive conclusion of our work will be presented in the following chapter.

CHAPTER V

CONCLUSIONS AND FUTURE WORK

5.1 <u>Conclusions</u>

In this work, two different schemes to alleviate the flooding problem in wireless ad hoc reactive routing protocols were proposed. We investigated the flooding issue in Ad Hoc On-Demand Distance Vector (AODV) routing protocol and proposed Modified AODV (MAODV) with a hierarchical approach to tackle the problem. Such hierarchy reduces number of nodes involved in the route discovery procedure and consequently adds to the efficiency of the routing protocol. Our simulation results demonstrated proposed approaches helped mitigation of flooding. Because of reduction in flooding, significant improvements in performance metrics, namely normalized overhead, average delay per packet and packet delivery ratio are achieved.

In our second proposed scheme, namely CLAODV, we sought flooding optimization from a cross-layer design point of view. We explained how Contention Window (CW) of IEEE 802.11 can be used in our algorithm to optimize routing decisions of the network layer. It was shown in our proposed approach that assigning a contention window threshold can avoid routing in congested areas of the network. Our simulation results also proved the strength of our cross-layer design based approach. Again, improvements were seen in network performance metrics when we compared to AODV and only delay performance metric showed a slight decline.

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Finally, it was shown via computer simulations that by exploiting both approaches simultaneously, further improvements on the performance of the network are achieved. Our results clearly show that such combinational scheme outperforms AODV in all simulated network performance metrics.

5.2 Future Work

Although simulation results suggest that both proposed schemes significantly reduce flooding in the network, there remain some issues to be addressed in future. Wireless nodes in all simulations were assumed to be static in the sense that no mobility occurs in the network. In future, the performance of our proposed protocols should be re-evaluated in a wireless ad hoc network where mobility may occur.

We proposed MAODV in order to tackle the flooding problem exists in AODV. We developed our hierarchical approach in MAODV, where nodes were classified as MN and FN. Yet, we employed a random FN selection mechanism which may be inefficient under some circumstances. To further optimize MAODV, we may need to work on an adaptive FN selection algorithm. This is considered for future in our research.

Cross-layer design showed to be a strong and effective approach to enhance network adaptivity by making more interactions between network layers in wireless environments. We proposed Cross-Layered AODV (CLAODV) in which IEEE 802.11 contention window was used in routing decisions of the protocol. In order to fairly judge the performance of CLAODV, we may need to design protocols in which other parameters from different layers of the network are exploited and then their performance compared

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to our model should be investigated. In future we may consider such exploitations by designing protocols that takes, for instance, node energy consumption into consideration.

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