Design and Evaluation of an IEEE 802.11 Based Dual MAC for MANETs

Dissertation

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Master of Technology

by

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under the guidance of

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Dedicated to
my mother
Smt. Manorama Rai

and
my father
Shri Harishchandra Rai

Dissertation Approval Sheet

This is to certify that the dissertation titled

Design and Evaluation of an IEEE 802.11 Based Dual MAC for MANETs

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Abstract

Multihop ad-hoc wireless networks offer great challenges for protocol designers. Stations in such networks are constrained by factors like low power, limited bandwidth, link errors, and collisions. Changes are needed at various levels of the protocol stack, most importantly at the medium access layer (MAC). The medium access mechanism in multihop wireless networks should minimize collisions, and take care of the hidden and exposed node problems. The IEEE 802.11 MAC with Distributed Coordination Function (DCF) does not scale well in such networks. We introduce Point Coordination Function (PCF) in the region of high traffic areas, and discuss its effect on network performance. To improve network scalability and throughput, we propose the design of a new MAC called *Dual MAC*. This work discusses architecture and working of the dual MAC in detail. Performance results of the network using dual MAC are presented, and compared with that of pure DCF operation.

Acknowledgments

I express my sincere gratitude towards my guides **Prof. Sridhar Iyer** and **Dr. Leena Chandran Wadia** for their constant help, encouragement and inspiration throughout the project work. Without their invaluable guidance, this work would never have been a successful one. I would also like to thank the members of the *Mobile Computing Research Group* at KReSIT, namely Srinath Perur, Vijay Rajsinghania, Vikram Jamwal, Deepanshu Shukla, Anupam Goyal, and Abhishek Goliya for their valuable suggestions and helpful discussions. Last, but not the least, I would like to thank the whole KReSIT family which made my stay at IIT Bombay a memorable one.

Satyajit Rai
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January 15, 2003

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Chapter 1

Introduction: Cooperative Ad-Hoc Networks

1.1 Introduction to Wireless Ad Hoc Networks

In recent times, the wireless networks have become very popular. Wireless LANs are being deployed on airports, conferences, etc. People have started using portable laptops to access Internet and other resources using wireless networks while moving. Another area which has generated a lot of interest recently, is wireless ad-hoc networks.

An ad-hoc network is formed when two or more stations come together to form an independent network. Ad-hoc networks are also termed as infrastructure-less networks since as they do not require any prior infrastructure. Two stations that are within transmission range of each other are called one hop neighbours. Multihop ad-hoc networks are ones in which the stations can talk to stations more than one hop away via intermediate stations.

Cooperative ad-hoc networks are formed by several homogeneous wireless stations. All the stations cooperate with each other, i.e., the traffic for the stations that are more than one hop away is routed by the intermediate stations. The intermediate stations are called relaying stations.

1.2 Multi-hop Wireless Networks

Cooperative multihop ad-hoc wireless networks consist of a group of stations connected to each other over one or more hops. If two communicating stations are more than one hop away, the intermediate stations route the packets from source to destination. Disaster management operations and battalion of soldiers are the example of applications of such cooperative ad-hoc wireless networks. Most often, the traffic in these networks is directed towards a central controlling station. The controlling central station is more capable than other stations and in most cases, can also communicate with headquarter/head office. The Figure 1.1 shows a multihop cooperative network with the central controlling station labeled A. The stations B, C, D and F are directly connected to station A over a single hop; the stations E, G, H, I and K are connected to the station A over two hops; and the station J is connected to station A over three hops.

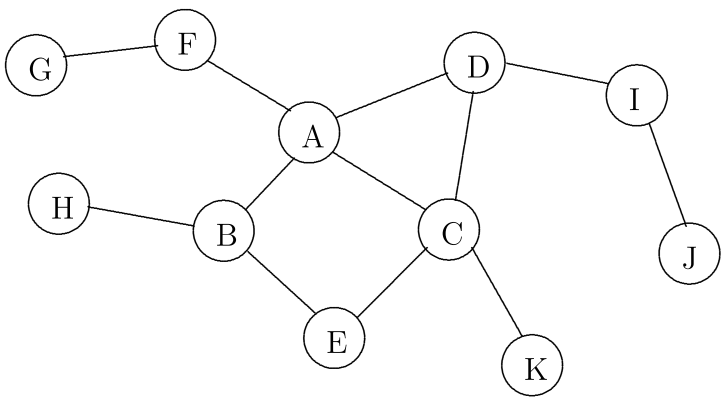

Figure 1.1: Multihop cooperative Network

1.3 Problems with Centralized Traffic

The traffic around the central stations (station A in Figure 1.1) is quite high owing to reason that most of the stations communicate with this station. In traditional sense, this model is like a client-server model where the central station acts as a server and all other stations are clients. The high traffic in the central region causes large number of collisions if the channel access mechanism is not designed carefully. This causes enormous throughput drop in the network. The problems associated with the centralized scenario and their solutions are discussed in detail in later chapters.

1.4 Requirements and Challenges of Multi-hop Wireless Networks

Multihop wireless networks are faced by challenges not present in the wired networks. Mobility of stations in wireless networks gives rise to issues like route changes and link failures. Unlike the wired networks, the main cause of errors in the wireless networks is due to errors on wireless channels. These reasons require changes at various layers of protocol stack.

1.4.1 IP and Routing

The stations in wireless network do not remain in the same subnet due to mobility; hence either their IP address needs to be changed and/or the packets be forwarded to them. These requirements have lead to development of mobile IP[1] where the addresses are assigned to mobile hosts dynamically and the packets are appropriately forwarded to them. Frequent link changes in ad-hoc networks cause change of routes between stations. This requires that the routing protocol take care of these changes and update the routes frequently. Special routing protocols like AODV[2], DSR[3] and DSDV[4] have been proposed for use in wireless ad-hoc networks. We will not discuss more about the IP and routing in this thesis.

1.4.2 MAC

The link characteristics in wireless environments is very different from that of wired networks. At link layer we have to face following challenges:

Bandwidth: Bandwidth is the one of the most scarce resource in wireless networks. The available bandwidth in wireless networks (2-10Mbps) is far less than the wired links (typically 100Mbps).

Range Issues: The transmission range of stations depends upon the transmitted power and various sensitivity values. Unlike wired networks all stations on a LAN can not listen to one another.

Power: The wireless stations are battery operated and therefore higher transmission power leads to faster degeneration of the batteries. On the other hand, if we keep transmission power too small, the stations may no longer be in range of each other.

Collisions: Since all stations can not listen to each other, transmission from two station may lead to collision at another station.

Link Errors: Channel fading and interference cause link errors and these errors may sometimes be very severe.

1.4.3 Physical: Hidden and Exposed Node Problems

The transmission range of stations in wireless network is limited by the transmission power, therefore, all the station in a LAN can not listen to each other. This means that normal carrier sense mechanism which assumes that all stations can listen to each other, fails. In particular, this gives rise to *hidden node* and *exposed node* problem. Consider stations **A**, **B**, **C** and **D** as shown in Figure 1.2. With reference to the Figure 1.2, *hidden* and *exposed* node problem can be described as follows:

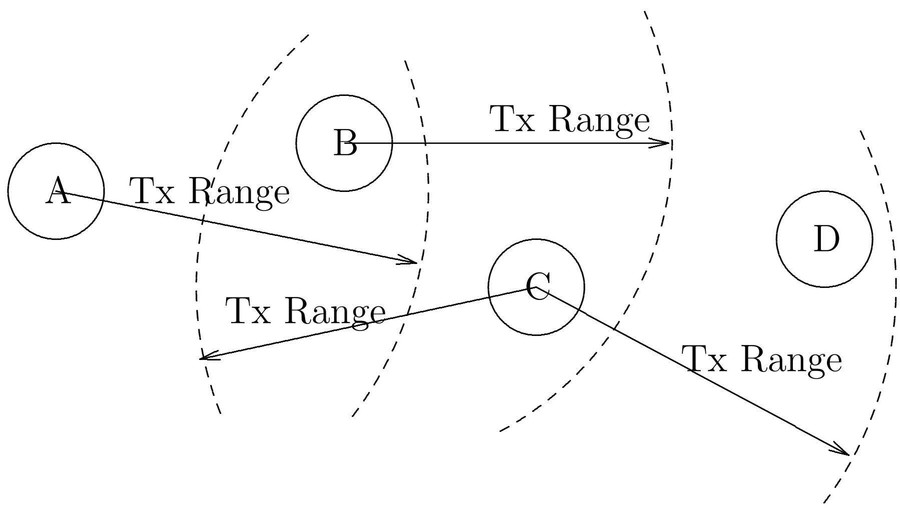

Figure 1.2: Hidden and Exposed Node Scenario

Hidden node Problem: Stations **A** and **C** become *hidden* to each other as station **B** can listen both to **A** and **C**, but stations **A** and **C** can not listen to each other. If a packet is being transmitted from station **A** to station **B** and station **C** decides to start a transmission (being hidden, it does not know of **A-B** transmission), there will be collision at station **B**.

Exposed node Problem: If station **B** is sending data to station **A**, then station **C** becomes *exposed* to **B** and is forced to be silent even if it can send data to another station. This is because station **C** finds carrier busy during transmission of station **B**.

A simple and elegant solution to the *hidden* node problem is to use small packets called **RTS** (Request to Send) and **CTS** (Clear to Send) for handshaking before transmission of data packet. This solution was proposed by Karn [7] in his MACA protocol for AX.25.

1.5 Thesis Objective and Scope

This work aims at improving the throughput in centralized cooperative wireless ad-hoc networks by use of stations equipped with a new MAC called *dual MAC* at one-hop boundary of the central coordinating station. The main focus of this work is to present the design and architecture of dual MAC. The implementation of Dual MAC in publicly available Network Simulator NS-2 is presented, and simulation results are discussed. The scope of this work is limited to centralized multihop networks to a large extent. The effect of node mobility is not considered.

1.6 Thesis Outline

The rest of the thesis is outlined in this section. In Second chapter, different medium access approaches, and the choices for MACs available for wireless networks are discussed. The operation of IEEE 802.11 MAC is discussed in detail. Third chapter discusses the operation of IEEE 802.11 MAC in multihop networks, and describes the problems of using the DCF and PCF in such scenario. In chapter four, we discuss our approach to improve the throughput of multihop ad-hoc networks, namely the design and architecture of dual MAC. The chapter five discussed the implementation of dual MAC in NS. The simulation set up and results are discussed in chapter six. Finally, thesis ends with the conclusion and the scope for the future work in chapter seven.

Chapter 2

MAC in Multi-hop Ad-Hoc Networks

2.1 Channel Access Mechanisms

The most important part of a MAC protocol is Channel Access Mechanism. The channel access mechanism is way of regulating the use of physical channel among the stations present in the network. It specifies when a station can send or receive data on the channel. In this section, we discuss three channel access mechanisms, namely *TDMA*, *CSMA/CA*, and *Polling*.

2.1.1 TDMA

Time Division Multiple Access (TDMA) is one of the simplest channel access mechanisms. In this method each station sends the data for a finite duration called time slot. Typically, each time slot has fixed duration. In TDMA scheme, there should be a way to figure out the time slot for the transmission. This is done by having a station called *Base Station* which is responsible for assigning the time slots to the stations. A set of time slots forms a TDMA cycle or frame which repeats at a regular duration. At the beginning of the time slot, the Base Station sends the allocation slots for the rest of the TDMA cycle and the stations send the Data in their corresponding time slots. Typically, the stations transmit on one frequency called *uplink frequency* and receive on another frequency called *downlink frequency*.

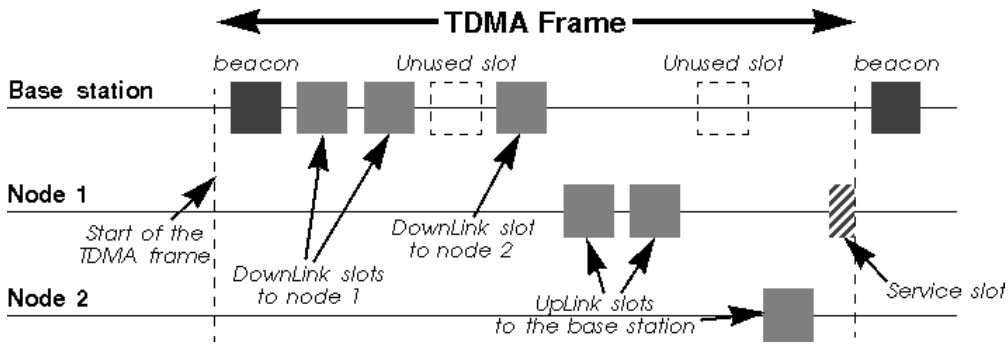

Figure 2.1: TDMA channel Access Mechanism

TDMA suits very well for telephone application because of very predictable traffic requirement and is used in cellular telephone networks. However, it does not suite the packet based applications where the data traffic is bursty and unpredictable. This is because TDMA is very strict and inflexible.

2.1.2 CSMA/CA

CSMA/CA (Carrier Sense Multiple Access) is derived from CSMA/CD (Collision Detection) which is the channel access mechanism used in wired Ethernets. Since the transmission range of wireless stations is limited, collision can not be detected directly. This protocols tries to avoid the collision. On arrival of a data packet from LLC, a station senses the channel before transmission and if found idle, starts transmission. If another transmission is going on, the station waits for the length of current transmission, and starts contention (i.e. waits for a random amount of time). Since the contention is a random time, each station get statistically equal chance to win the contention.

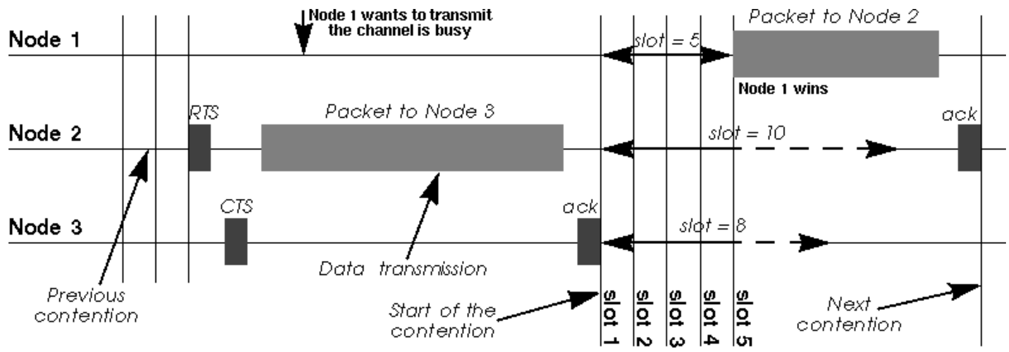

Figure 2.2: CSMA channel Access Mechanism

CSMA/CA is asynchronous mechanism for medium access and does not provide any bandwidth guarantee. Its a best effort service and is suited for packetized applications like TCP/IP. It adapts quite well to the variable traffic conditions and is quite robust against interference.

2.1.3 Polling MAC

Polling mechanism in wireless networks is a mix of TDMA and CSMA/CA access methods. The base station has total control over medium, but the frame size can be variable. The base station polls the stations in the network, and the stations reply with the data, if available. The base station can poll all the stations one by one or follow some intelligent reservation strategy to poll only those stations which have date to send. Polling is very much like TDMA, except that it is more flexible and allows variable length data packets.

TDMA and Polling methods have disadvantage of being centralized in nature, and therefore, are not suitable for multihop ad hoc networks. This is due to the fact that all the stations are not in transmission range of each other. CSMA/CA is distributed in nature, and hence, is suitable for multihop ad-hoc networks. However, it must be noted that a distributed medium access mechanism like CSMA/CD suffers from the disadvantage of causing collision under high load condition, i.e., if too many stations try to access the medium at the same time, chances of collision increase. One way to avoid

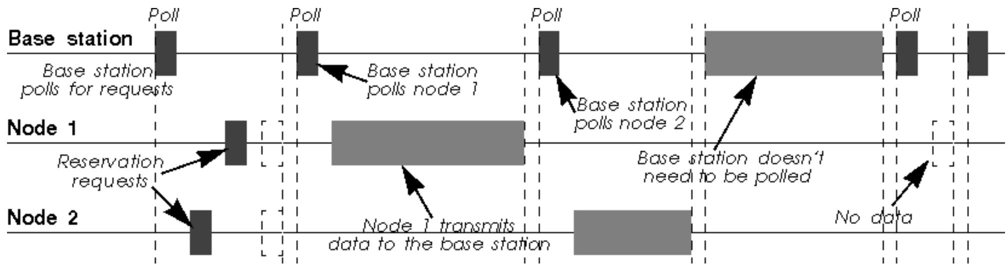

Figure 2.3: Polling Mechanism

this disadvantage is to intermix the Polling and CSMA/CA mechanism, as provided in 802.11 PCF mode of medium access.

The most suitable access mechanism for ad hoc networks is the CSMA/CA as it is distributed and simple in nature. Another reason for using CSMA/CA in wireless MACs is that wireless LAN cards with CSMA/CA are readily available.

2.2 Available MACs

2.2.1 IEEE 802.11 MAC

The IEEE 802.11 MAC was designed by a committee of IEEE. The goal of the committee was to create a MAC standard for wireless LANs. In the 802.11 committee, each vendor has pushed its own technology and specifications. The result is that the standard is very versatile and well designed including all the optimizations and clever techniques developed by different vendors. The standard specifies one MAC protocol and three physical standards: Frequency Hopping 1Mb/s (Only), Direct Sequence 1 and 2 Mb/s and diffuse infrared. Subsequently, the standard has been extended to support 2 Mb/s for Frequency Hopping and 5.5 and 11 Mb/s for Direct Sequence (802.11b). The MAC has two main modes of operation, a distributed mode (CSMA/CA), and a coordinated mode. 802.11 also uses MAC level retransmissions, RTS/CTS and fragmentation. The standard also has optional power management features and optional authentication and encryption (using the WEP, Wired Equivalent Privacy). Now the standard has also been extended to be used in 5GHz band (IEEE 802.11a) and some extensions have been added in 2.4GHz band (IEEE 802.11b) to increase the bandwidth.

2.2.2 HiperLan-I

The HiperLan standard has been developed by researchers at ETSI (European Telecommunications Standards Institute). It is developed without any strong vendor influence and is quite different from existing products. The standard is quite simple, and uses some advanced features. It works in dedicated bandwidth (5.1GHz to 5.3GHz) and so does not have to use spread spectrum. The signalling rate is 23.5Mb/s, and 5 fixed channels are defined. The protocol uses a variant of CSMA/CA based on packet time to live and priority, and MAC level retransmissions. The protocol includes optional encryption (no algorithm mandated) and power saving.

The nicest feature of HiperLan (apart from the high speed) is the ad-hoc routing: if your destination is out of reach, intermediate nodes will automatically forward it through the optimal route within the HiperLan network (the routes are regularly automatically recalculated). HiperLan is also totally ad-hoc, requiring no configuration and no central controller.

The main deficiency of HiperLan standard is that it doesn't t provide real isochronous services (but comes quite close with time to live and priority), doesn't t fully specify the access point mechanisms and hasn't really been proved to work on a large scale in the real world. Overhead tends also to be quite large (really big packet headers).

2.2.3 HiperLan-II

HiperLan II was the first standard to be based on OFDM modulation. Each sub-carrier may be modulated by different modulations (and use different convolutional code, a sort of Forward Error Correction, FEC), which allow to offer multiple bit-rates (6, 9, 12, 18, 27 and 36 Mb/s, with optional 54 Mb/s), with likely performance around 25 Mb/s bit-rate. The channel width is 20 MHz in 5MHz band, and includes 48 OFDM carriers used to carry data and 4 additional are used as references (pilot carriers - total is 52 carriers, 312.5 kHz spacing).

HiperLan II is a Wireless ATM system, and the MAC protocol is a TDMA scheme centrally coordinated with reservation slots. Each slot has a 54 B payload, and the MAC provide SAR (segmentation and reassembly - fragment large packets into 54 B cells) and ARQ (Automatic Request - MAC retransmissions). The scheduler (in the central coordinator) is flexible and adaptive, with a call admission control, and the content of the TDMA frame change on a frame basis to accommodate traffic needs. HiperLan II also defines power saving and security features. HiperLan II is designed to carry ATM cells, but also IP packets, Firewire packets (IEEE 1394) and digital voice (from cellular phones). The main advantage of HiperLan II is that it can offer better quality of service (low latency) and differentiated quality of service (guarantee of bandwidth).

The IEEE 802.11 standard is the most widespread standard and has been deployed in wireless LANs. It is also being used in ad-hoc network testbeds, and lot of research is going on adapting 802.11 for ad-hoc networks. Besides that, it offers both infrastructure mode and infrastructure-less mode of operation and both can coexist together without any modifications. These factors make 802.11 MAC very suitable for ad-hoc networks and this thesis discusses the ad-hoc networks using 802.11 MAC.

2.3 IEEE 802.11 Operation

The IEEE 802.11 MAC offers two kinds of medium access methods, namely Distributed Coordination Function (DCF), and Point Coordination Function (PCF). DCF is the basic access method in 802.11 and requires no infrastructure. When wireless stations are within transmit range of each other, they form a Basic Service Set (BSS), and can communicate to each other using DCF. If the BSS contains only two stations, it is called Independent Basic Service Set (IBSS). Many BSSs may be connected by a Distribution System (DS) to form an Extended Service Set (ESS). An access point (AP) is the station that provides access to DS services. The PCF is built on the top of the DCF, and is also referred to as infrastructure mode. It requires a polling station called Point Coordinator (PC), which acts as controlling station during poll. The PCF consists of alternating Contention Free Periods (CFP) and Contention Periods (CP). During CFP, the PC polls other stations in the medium, and during CP, the access method becomes DCF.

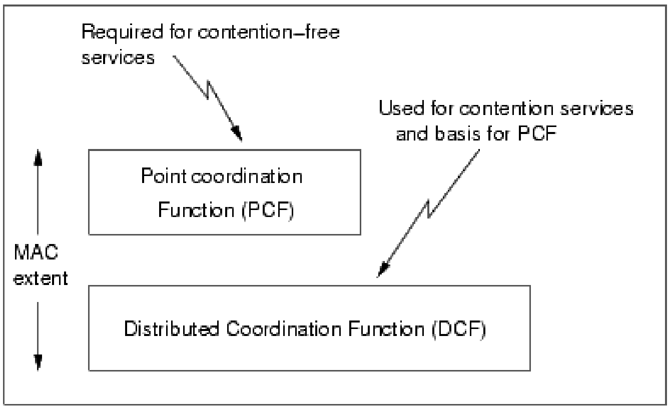

Figure 2.4: IEEE 802.11 Architecture

2.3.1 DCF Operation

The DCF is the fundamental access method used to support asynchronous data transfer on a best effort basis. The DCF is based on CSMA/CA. The carrier sense is performed at both the air interface, referred to as *physical carrier sensing*, and at the MAC sublayer, referred to as *virtual carrier sensing*. Physical carrier sensing detects presence of other users by analyzing the activity in the channel through the received signal strength.

A station performs virtual carrier sense by examining the received MPDU (MAC Protocol Data Unit) information in the header of RTS, CTS and ACK frames. The stations in BSS use this information to adjust their Network Allocation Vector (NAV), which indicates amount of time that must elapse until the current transmission is complete and the channel can be sampled again for idle status.

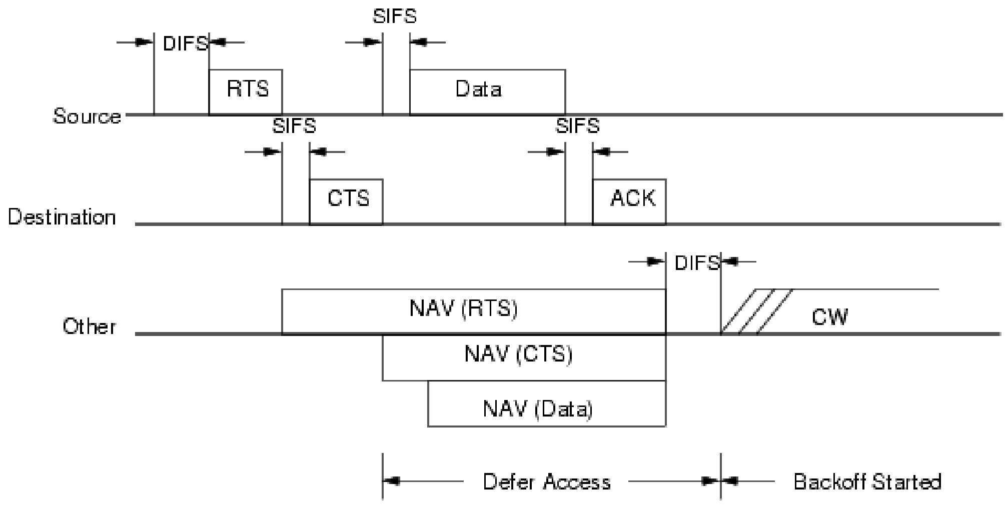

Figure 2.5: DCF access using RTS/CTS

Priority access to the medium is controlled through the use of mandatory interframe space (IFS) time intervals between the transmission of frames. Three IFS intervals are specified in the standard: Short IFS (SIFS), PCF-IFS (PIFS), and DCF-ISF (DISF). The SIFS is the smallest and the DIFS is the largest. The SIFS has the highest priority to access communication medium. For basic access method (without RTS/CTS), the station waits for DIFS period and samples the channel again. If the channel is still idle the station transmits MPDU. If the receiving station receives the packet correctly, it sends an ACK after waiting for the SIFS time. If RTS/CTS is used then the station sends a RTS packet before sending MPDU. On receiving RTS, the receiving station sends a CTS frame after SIFS time. On receiving CTS, the sender waits for SIFS time and transmits the MPDU. Again, the ACK follows after SIFS period. It is also possible to send the multiple fragments of a MPDU, where ACK to each fragment is sent after SIFS time, and next fragment is sent after SIFS time of ACK.

The collision avoidance portion of CSMA/CA is performed through a random backoff procedure. If a station initially senses the channel busy; then the station waits until the channel becomes idle for DIFS period, and then computes a random backoff time within a range called backoff window. For IEEE 802.11, time is slotted in time periods that corresponds to a Slot_Time. After each unsuccessful attempt, the backoff window is increased exponentially until a maximum value. The idle period after the DIFS period is called contention window (CW). The advantage of this channel access method is that it promotes fairness among stations, but its weakness is that it can not provide delay bound service to the stations.

2.3.2 PCF Operation

The 802.11 MAC offers contention free service by means of PCF. PCF is optional capability and provides contention-free (CF) frame transfers. The PCF relies on the point coordinator (PC) to poll other stations. The polled stations can send the data without contending for the medium. In a wireless LAN, the function of a PC is performed by AP within each BSS.

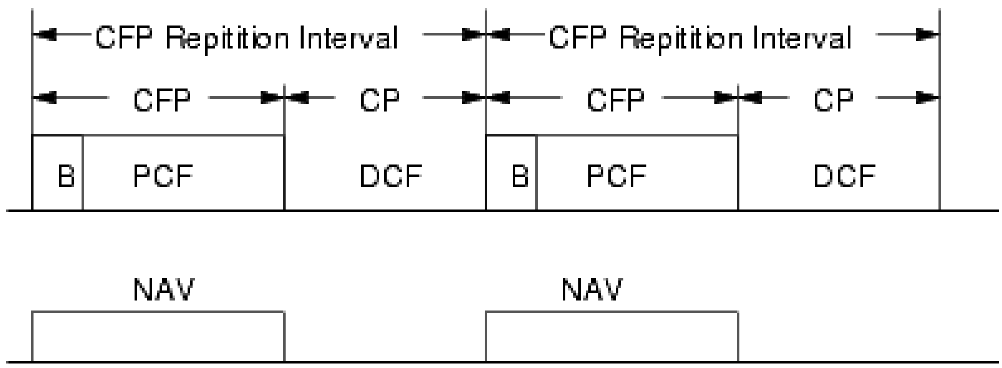

Figure 2.6: PCF access

The PCF is required to coexist with the DCF and logically sits on the top of DCF (see Figure 2.4). The PCF consists of alternating contention free period (CFP), and contention period (CP) as shown in figure 2.6. In the CFP, the PC polls each of the stations present in the BSS. The PC specifies the start of the CFP by sending a beacon that contains the length of CFP duration, among other things. All the stations in the BSS set their NAV for the duration of the CFP. The PC terminates the CFP by sending a CF-End frame, and may also terminate it before the advertised CFP duration. The time difference between two beacons is called beacon period (BP) or CFP repetition interval, and is a multiple of beacon frame. The beacon also helps in synchronization and timing. The limits on durations of each of the frames are described in the IEEE 802.11 standard [5]. In the CP, the stations use DCF to access the medium.

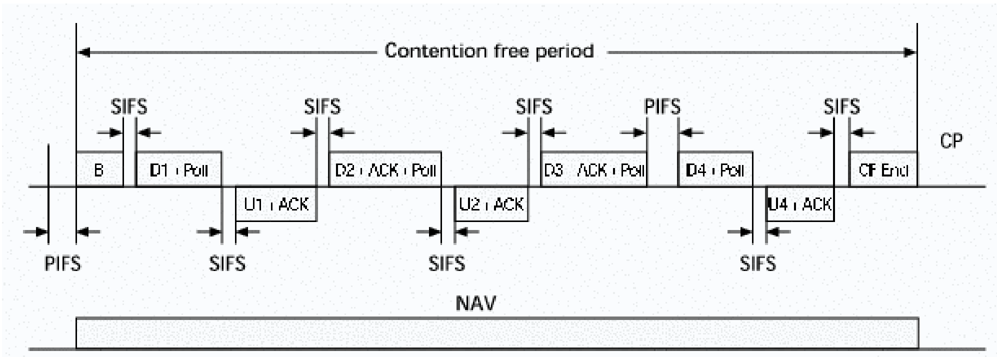

Figure 2.7: PCF Transmissions

In CFP, the PC polls each station by sending either Poll, Data + Poll or Data + ACK (for previous frames) + Poll. The polled station sends the data or Data + ACK (if polled by Data+Poll frame) to PC in response to the PC's poll. It is also possible to have station to station transmission during the CFP. The PCF offers connection oriented polled service and therefore it reduces contention to a large extent. It is ideal for wireless LAN environments where all the stations are connected to the AP over a single hop. However, at low traffic the overheads are quit high.

2.3.3 Summary

The DCF is suitable for the ad-hoc contention based service, whereas the PCF offers polling based service. The DCF can exist independently in a network, but the PCF coexists with the DCF. The DCF can be easily deployed in ad-hoc networks, as it does not require any infrastructure (like AP in case of PCF). The PCF can provide connection oriented service but is suitable largely for the one-hop wireless LAN setup. However, simply using PCF in central part of the multihop network is not enough as the stations in the PCF mode do not use RTS/CTS exchange during CFP. The lack of RTS/CTS exchange results in hidden and exposed node problems. We discuss this scenario in greater detail in next chapter, and propose the solution to the problems encountered by simple DCF/PCF operation of IEEE 802.11 MAC in multihop networks.

Chapter 3

IEEE 802.11 MAC in Multi-hop Scenario

3.1 Multihop Scenario

The IEEE 802.11 MAC is designed for wireless LANs. The requirements of multihop ad-hoc networks are more challenging than those of wireless LANs. In this chapter, we investigate the operation of IEEE 802.11 MAC in centralized multihop ad-hoc networks. The terms *station* and *node* are used interchangeably throughout the thesis. Multihop cooperative wireless ad-hoc networks will be simply referred to as *multihop networks*.

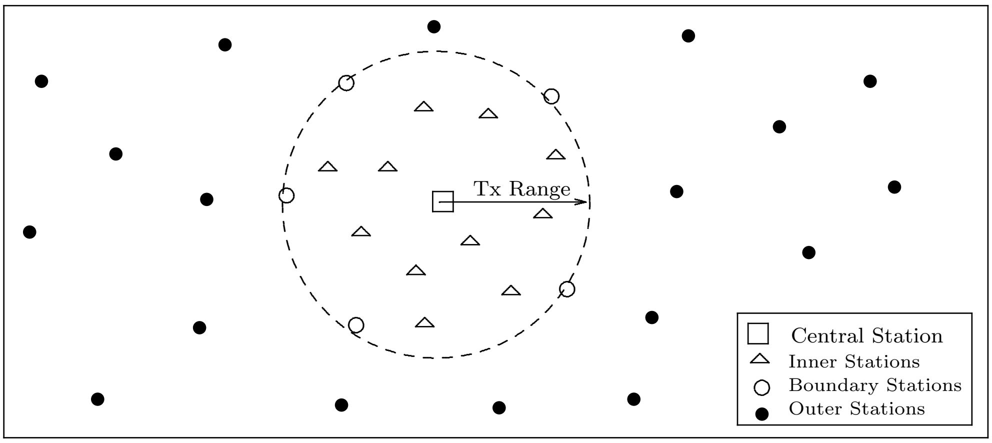

Figure 3.1: Multihop Scenario

Consider a multihop centralized scenario, as shown in the figure 3.1. For convenience, the stations inside the network are classified into following categories:

Central station is the central controlling station. Most of the traffic in the network is directed towards it.

Inner stations are within one hop boundary of the central station.

Boundary stations are at one hop boundary of the central station. These stations act as relaying stations for the stations outside the reach of central node.

Outer stations are outside the communication range of central node.

3.2 IEEE 802.11 Operation in Multihop Networks

The 802.11 MAC with DCF mode of operation is the simplest choice in multihop ad-hoc networks. The reason for the choice of DCF is that it does not require any prior infrastructure. Two or more stations can come together and form an BSS. This nature of DCF is very suitable for ad-hoc networks as the ad-hoc networks are simply formed by as set of stations coming together. In this section we discuss the operation of 802.11 MAC in multihop networks, especially centralized multihop ad-hoc networks

In a centralized multihop network, as shown in Figure 3.1, the node density in central region is higher than in the outer region. Most of the traffic is directed toward the central node and boundary stations act as relaying stations. Therefore, the traffic near the central station and its one hop neighbours is very high. Since the DCF is a contention based distributed protocol, it performs badly in high load conditions. The poor performance of DCF is due to fact that the collisions increase as more and more stations try to access the medium at the same time. It is well known that the polling MAC performs better than pure CSMA/CA under high load conditions. Therefore, contention can be decreased by using polling MAC where central station acts as polling station.

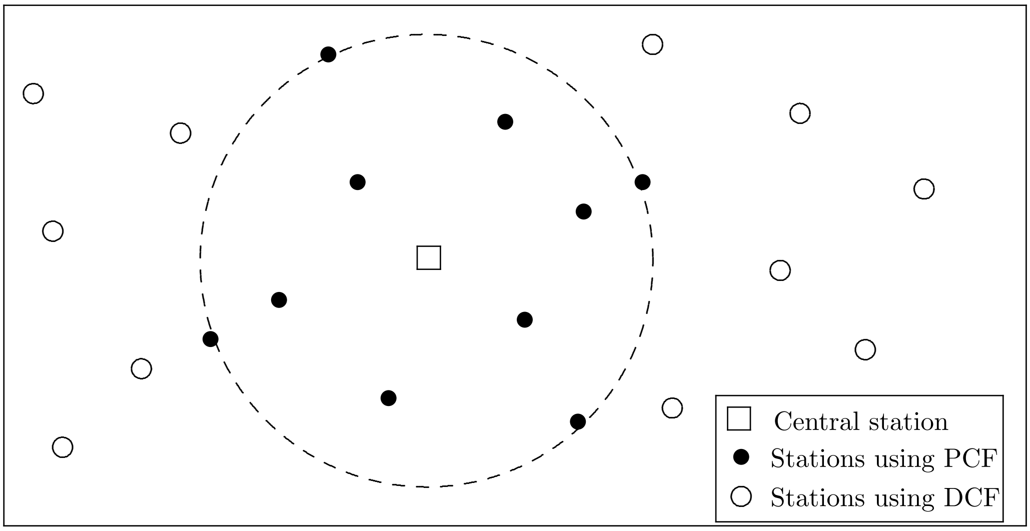

Figure 3.2: Hybrid PCF-DCF Operation

The most suitable choice for the polling MAC would be PCF mode of 802.11, as it is an extension of the DCF mode. Ebert et. all [8] have shown that the PCF mode performs better than DCF when the number of stations in WLAN cell is very high. Therefore, we make the central node as Point Coordinator (PC), and it polls all the inner and boundary nodes during CFP period. This differs from conventional PCF operation in WLANs where PC resides within AP. The outer stations still perform DCF since the traffic in those regions is not high. The outer stations can send their data in contention period (CP) as all the stations perform DCF during CP. We refer this combination of PCF and DCF as *hybrid* operation as shown in figure 3.2.

The hybrid operation seems to be an ideal choice in multihop networks, but it gives rise to following problems:

- The stations that are polled by the Point Coordinator (PC) keep their NAV set during the CFP period, and therefore, can not receive from outer stations. It can also be said that the boundary nodes become exposed to PC.

- Outer stations become hidden to PC, and vice versa, as there is no RTS/CTS exchange between PC and its one hop neighbours during CFP period.

The Figure 3.3 shows that there is no throughput gain with hybrid mode as compared with pure DCF mode. In fact, hybrid mode performs worse than DCF especially under low load.

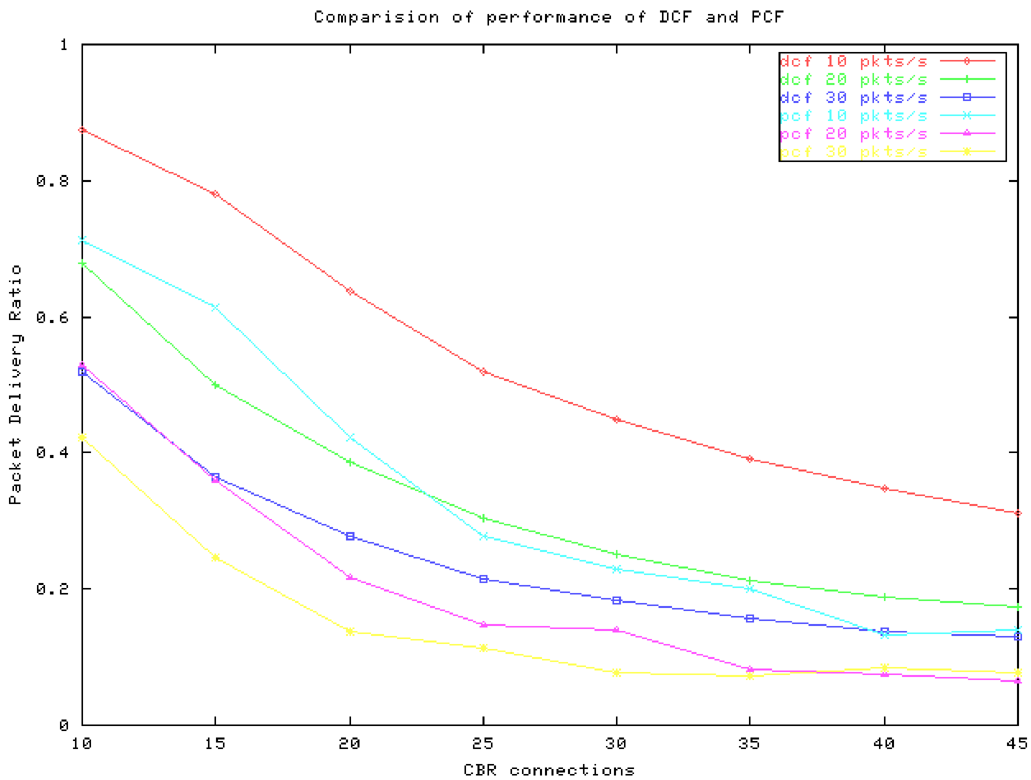

Figure 3.3: Comparison of DCF and PCF in Multihop Networks

Due to the above problems, PCF at center does not increase throughput, as is expected. Shugong Xu and Tarek Saadawi [9] have also shown that the 802.11 MAC does not perform well in multihop ad hoc networks. This leads to conclusion that without modifications, 802.11 MAC with DCF mode or with PCF at center is not very suitable for multihop ad hoc networks.

3.3 Problem Description

Simple DCF is not suitable for centralized multihop network due to collisions at high traffic. A polling MAC (PCF) is required at the center of the network to handle high traffic and reduce collision, but it gives rise to hidden and exposed node problems. The solution to both of these problems is provided by introducing *dual Nodes* at the boundary of the central node. The details of the dual node and its architecture are discussed in next chapter.

Chapter 4

Dual MAC

4.1 Need for Dual MAC

The centralized multihop ad hoc networks, as explained in earlier chapters, require a MAC that can provide distributed access mechanism. Furthermore, the MAC should be able to handle high traffic in central region. The pure DCF operation, or *hybrid* operation (see Fig. 3.2) do not perform efficiently in multihop networks. The reasons for this inefficiency, as explained in section 3.2, are:

1. The DCF does not work well in high load scenario.

2. In case of hybrid operation, the polling and NAV setting in PCF nodes cause exposed and hidden node problems, thereby decrease the throughput.

To improve the throughput, boundary nodes should be able to receive date from outer nodes during the CFP period (NAV is set). For this the MAC should be able to receive even if its NAV is set. Also, transmissions from outer stations should not collide with that of PC at boundary stations. To address above problems, we propose to equip boundary stations with *dual MAC*.

4.2 Overview of Dual MAC

A *dual node* is a station which has two independent MACs each communicating on different logical channels. The two MACs are encapsulated inside the dual MAC. The logical channels could be FDMA or CDMA. Consider the boundary stations in Figures 3.1 and 3.2 that are equipped with dual MACs. One of the MACs uses the PCF and is termed as PCF MAC. The second MAC uses the DCF and is termed as DCF MAC. The PCF MAC communicates with the PC, and the DCF mac communicates with the outer nodes. The exposed and hidden node problems in central region (see section 3.2) are eliminated as follows:

- Boundary stations use the PCF and the DCF on different channels. Therefore, the transmission of outer node does not collide with that of PC, and vice versa.

- The DCF MAC in the dual node can receive from outer nodes even when the NAV of PCF MAC is set during CFP period, thereby eliminating exposed node problem.

4.3 Architecture of Dual MAC

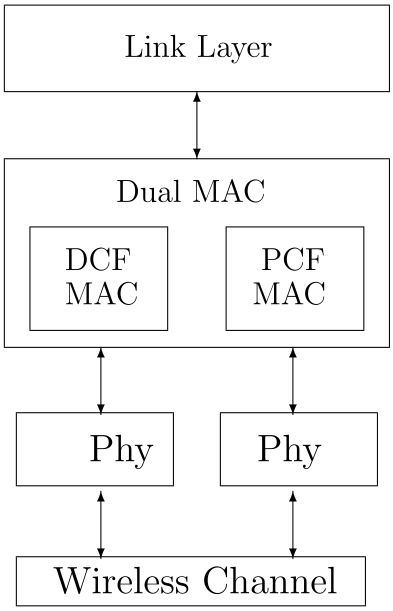

Figure 4.1: Architecture of Dual Mac

The dual MAC consist of two MACs in a single station each capable to send and receive packets independently. Each MAC is designed to operate on different logical channels. As mentioned earlier, the channels can be either FDMA or CDMA but it does not make difference as far as the design of the dual MAC is concerned. As shown in Figure 4.1, the dual MAC is below the Link Layer and basically encapsulate two actual 802.11 MACs. These two MACs which we refer to as PCF MAC and DCF MAC respectively, communicate on two different logical channels. The DCF MAC talks to the stations that are operating in DCF mode and the PCF MAC talks to the PC and other stations which are in PCF mode. The dual MAC is a layer on the top of these MACs and single point of interface to the Link Layer (LL). For all down-going packets the dual MAC layer acts as arbitrator and sends on either of the MAC below it. For the up-going packets, the job of dual MAC is simply to hand over the packet to the link layer.

4.4 Operation

A packet arriving from link layer is received by the dual MAC and handed over to the MAC at appropriate frequency. The link layer finds out the MAC address of the next hop destination by using ARP and hands out the packet to the dual MAC layer along with the destination MAC address. In case dual MAC, the dual MAC also needs to know the channel of the destination station. This could be done either by ARP table maintaining information about the channel on which the destination stations is communication, or by maintaining a local list of stations on each channel. The dual MAC figures out the channel of the destination MAC and sends out the packet to the appropriate MAC. The broadcast packets like route discovery packets and ARP packets are sent to both the

```
For outgoing packets:
        if ( packet is broadcast ) {
                send packet to both PCF MAC and DCF MAC;
        } else {
                channel = get_destination_MAC_channel();
                if ( channel == DCF_channel )
                        send packet on DCF MAC;
                else
                        send packet on PCF MAC;
        }


For incoming packets:
        hand over the packet to Link Layer;
```

Figure 4.2: Operation of Dual MAC

MACs. On receiving a packets from lower layer, the dual MAC simply hands it out to the link layer. The operation of the dual MAC is summarized in figure 4.2

4.5 Design Considerations

The dual MAC is essentially a MAC which can access two separate logical channels. This can be done in either half duplex way or in full duplex way. In half duplex method, the logical channel (radio frequency in case of FDMA, PN code in case of CDMA) is changed by the radio for a different channel to be accessed. In full duplex method, both the channel are accessed simultaneously. This requires that two different radios be employed for full duplex operation. We choose the full duplex operation since it offers parallelism of channel access which is essential for the boundary nodes. This requires extra cost, but the addition in cost is justified considering that very few stations need to be equipped with the dual MAC.

In the next chapter, we describe the implementation of dual MAC in the public domain Network Simulatior NS-2 in greter detail.

Chapter 5

Dual MAC Implementation in NS

5.1 Existing Node Architecture in NS

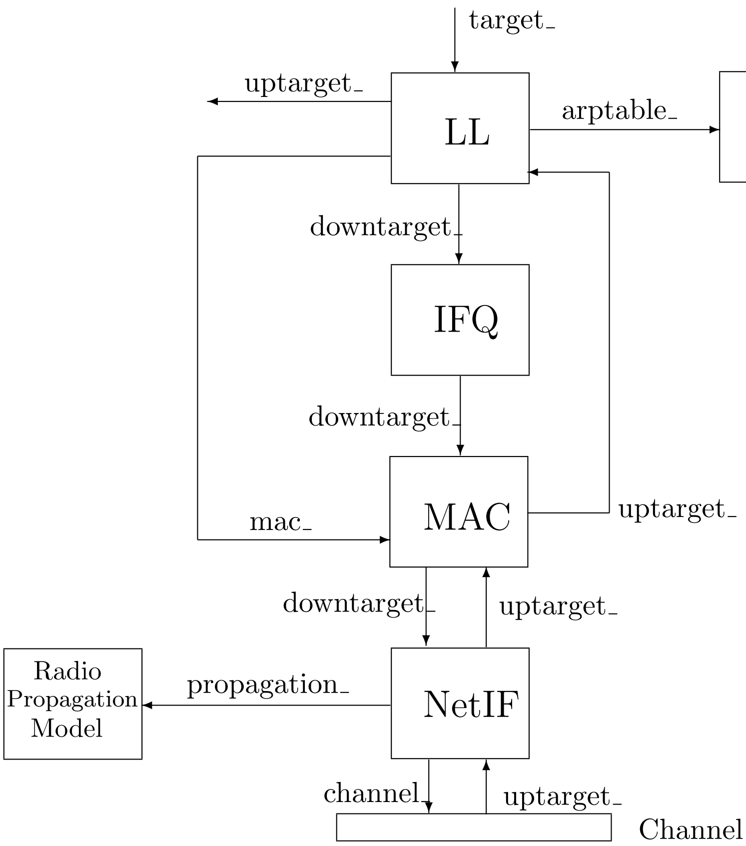

Figure 5.1: Architecture of NS Node

The Figure 5.1 shows the architecture of a NS mobilenode below the Link Layer. The outgoing packets after being processed by the routing layer, are handed over to the link layer (LL object) through the `target_` interface. The link layer is connected to the ARP module (ARP object) through the interface `arptable_`. After processing the packet and resolving MAC address through ARP, the link layer hands over the packet to the Interface Queue (IFQ object) through the `downtarget_` interface. The interface queue is connected to the MAC layer (MAC object) through interface `downtarget_`, and the packets are pulled off by the MAC when required. The link layer also contains a reference to MAC through the `mac_` interface. After the MAC has acquired the medium, it sends it to the physical layer (NetIF object) through the interface `downtarget_`. The physical layer sends this packet over the channel (Channel object) through the `channel_` interface and the packet reaches to the physical layer of the station at the other end of the link.

The outgoing packet is handed over by Channel to the physical layer through the `uptarget_` interface. The physical layer determines the received power levels through propagation model (`propagation_`) and processes the packet. The packet after processing, is handed over to the MAC layer through `uptarget_` interface. The MAC layer processes the packet and handles over to the link layer through the interface `uptarget_`.

5.2 Node Architecture of Dual MAC

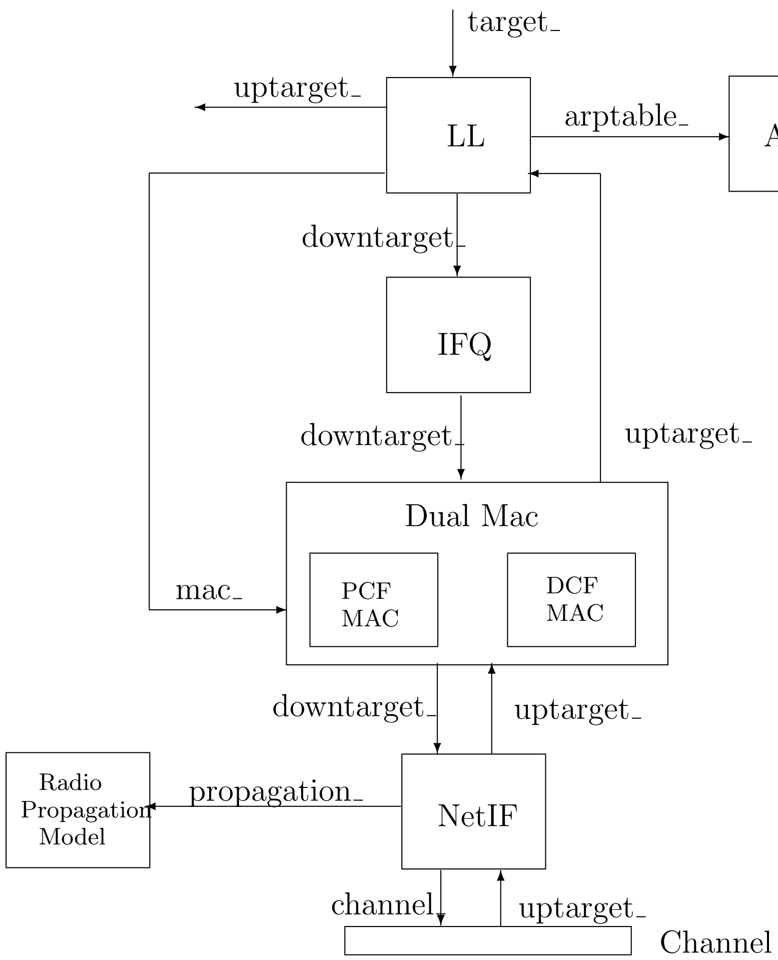

Figure 5.2: Architecture of Dual Node

The figure 5.2 shows the architecture of the dual Node. The dual Node differs from the architecture of the original NS node object only at the MAC layer. The MAC layer consists of a dual MAC object which encapsulates two 802.11 MAC objects within it.

All the upcoming and downgoing packets are first received by the dual MAC. In case of downgoing packets, the dual MAC determines the channel on which this packet is to be sent, and handles it over to appropriate MAC. In case of ingoing packets, it simply hands over the packets to the MAC corresponding to received channel where it is handed to link layer after processing.

5.3 Implementation in NS

```
Dual_Mac :: recv(packet)
{
        channel_id = channel id in packet header;
        if ( received packet is beacon ) {
                pcf_channel_id = channel_id;
                PC = address of sender;
        }

        if ( direction == DOWN AND packet is broadcast) {
                send packet on DCF MAC;
                send packet on PCF MAC;
                return;
        }

        if ( direction == DOWN AND destination == PC ) {
                send packet on PCF MAC;
                return;
        }

        if ( direction == UP AND channel_id == pcf_channel_id ) {
                send packet on PCF MAC;
                return;
        }

        send packet on DCF MAC;
        return;
}
```

Figure 5.3: Dual MAC implementation in NS

The pseudo code for working of dual MAC in NS is shown in Figure 5.3. The dual MAC (class *Mac_Dual*) is implemented by deriving the existing *Mac* class in NS. The *Mac_Dual* object encapsulates two actual *Mac_802_11* objects. The *Mac_802_11* class and *Packet* class have also changed to incorporate dual MAC functionality. The *Mac* class has been change to incorporate the features necessary for the dual MAC. The logical channels are implemented by incorporating a variable *channel_id_* in the packet header. The undesired packets (packets of different channel) are filtered by examining this variable in the received packet header. For the filtering, the changes have been done to *Mac_802_11* class. Each outgoing packet from MAC has its *channel_id_* variable set to appropriate channel. All interfaces like `uptarget_`, `downtarget_`, etc. have been changed such that all the packets that are received either from the Physical Layer or Link Layer are first received by the dual MAC.

As pointed out in section 4.4, the determination of channel for an outgoing packet can be either done by changing ARP module or by using a local list of stations on each channel. Currently the second approach is being used. The dual MAC stores the channel-id of the PC in a variable as all the traffic for PCF MAC goes only to the PC. All the packets that are destined for PC are sent on PCF MAC. For incoming packets, the channel-id is determined from the packet header and packet is handed over to appropriate MAC. The corresponding MAC updates its state and after processing the packet and hands it over to link layer.

Chapter 6

Simulation and Results

6.1 Simulation Setup

This chapter describes the simulation of dual MAC. The simulation are done by using the public domain simulator NS-2. The following assumption are made in the simulation:

- The effect of propagation delay on the model are neglected. This is fairly realistic considering the fact the area in which stations are present is limited to 1500mx1000m and inter-node distance is of the order of few hundred feet.
- The effect of channel errors is ignored in the simulations.
- No stations are operating in power save mode.

A finite buffer is maintained at each station. If the buffer fills, the newly generated packets are simply dropped. The safe distance upto which a stations can receive is maximum 250m. The interference range is 500m. All the packets in the DCF mode are sent using RTS/CTS exchange. We use constant bit rate (CBR) traffic with data packet size of 512 bytes. The routing protocol used is DSDV. The reason for choosing DSDV protocol for routing is that it provides constant routing overhead in case of static and less mobile networks.

6.2 Simple Scenario and Results

In order to gain an understating of the dual MAC, we set up a simple scenario as shown in Figure 6.1. The number of stations in the topology is 18. The receiving stations for all the transmitting stations is the station labeled **0**. The stations numbered **1**, **2**, **3**, **4**, **5**, and **6** are *inner* nodes. These stations are within one hop distance of the station **0**. The stations **7**, **8**, and **9** are the *boundary* nodes. Rest of the stations in the network are the *outer* stations.

The Figure 6.2 shows the performance of the dual MAC as compared to the DCF MAC. The number of connections is 15, and the packet rate is varied to increase the load on the network. It can be observed that as the load on the network increases, the throughput of network with dual nodes becomes better than that of network with DCF nodes only. The graph of packet delivery ratio for with respect to offered load is shown in Figure 6.3.

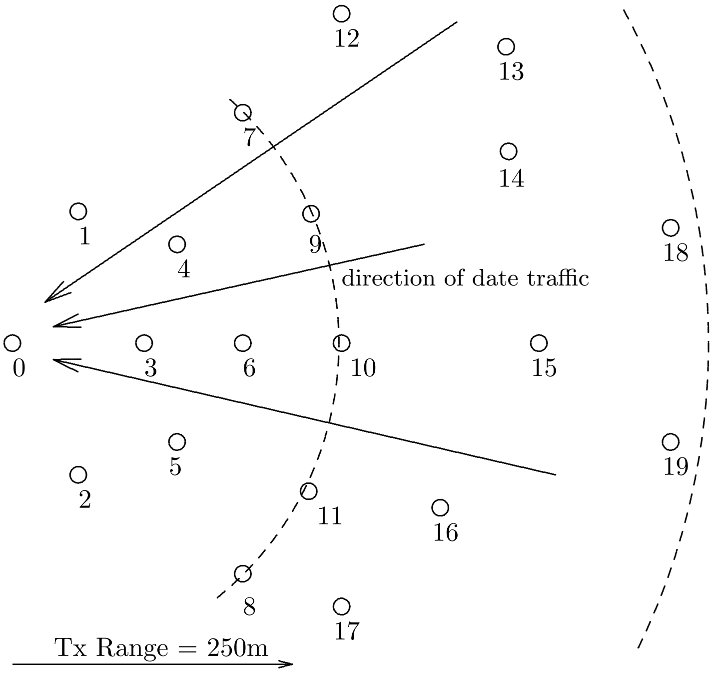

Figure 6.1: Simple Scenario

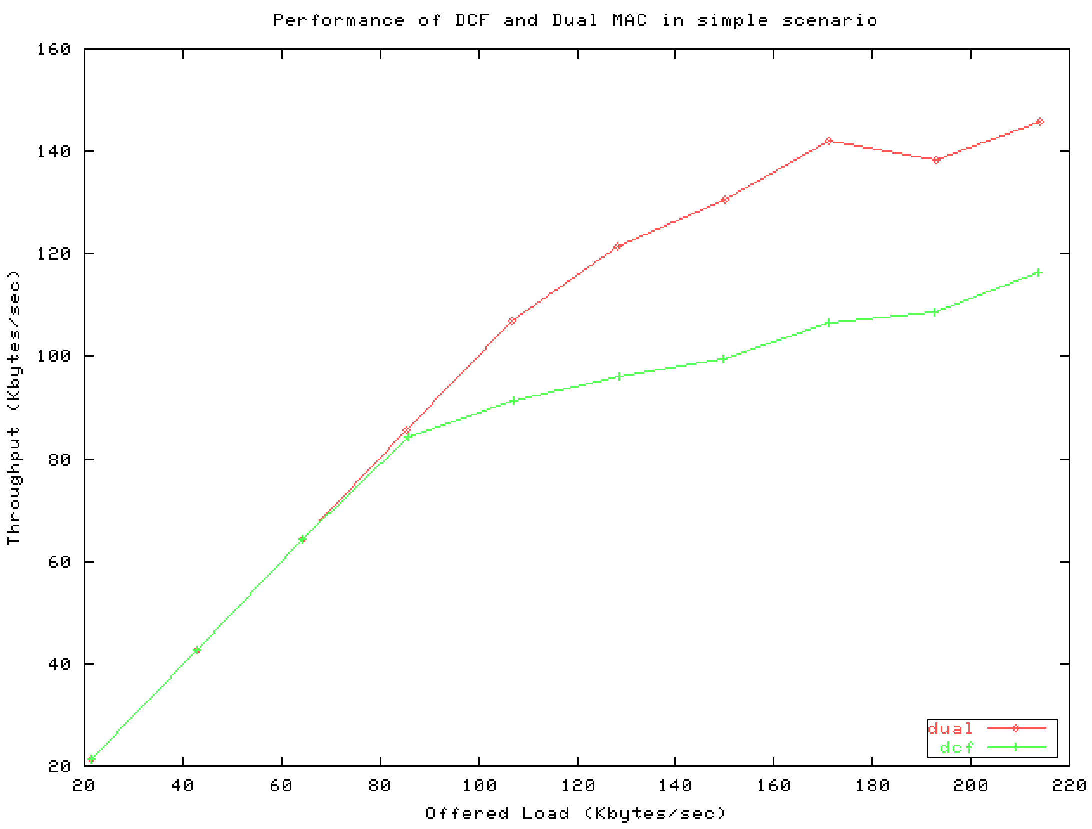

Figure 6.2: Throughput comparision of Dual MAC Vs DCF MAC in simple scenario

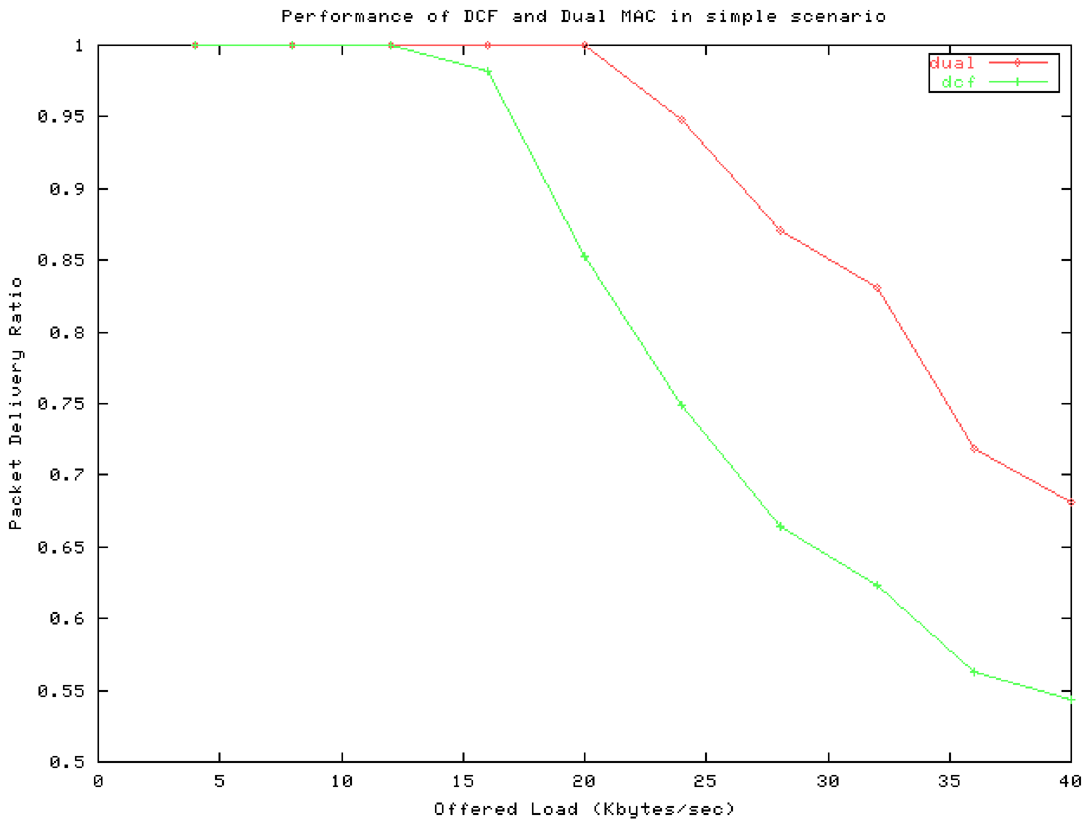

Figure 6.3: Packet Delivery Ratio for Dual MAC Vs DCF MAC in simple scenario

6.3 Generic Scenario and Result

In this section we describe the simulation results with random node placement. The stations are placed in an area of size 1500m x 1500m. The center station is placed at the coordinate (750m, 750m). There are 8 boundary nodes placed symmetrically around the central station each at the distance of 200m from the central station. The number of inner nodes in the topology is 12, and all other stations are more than one hop away from the central stations. The maximum number of hops is six. The stations are randomly placed in the area.

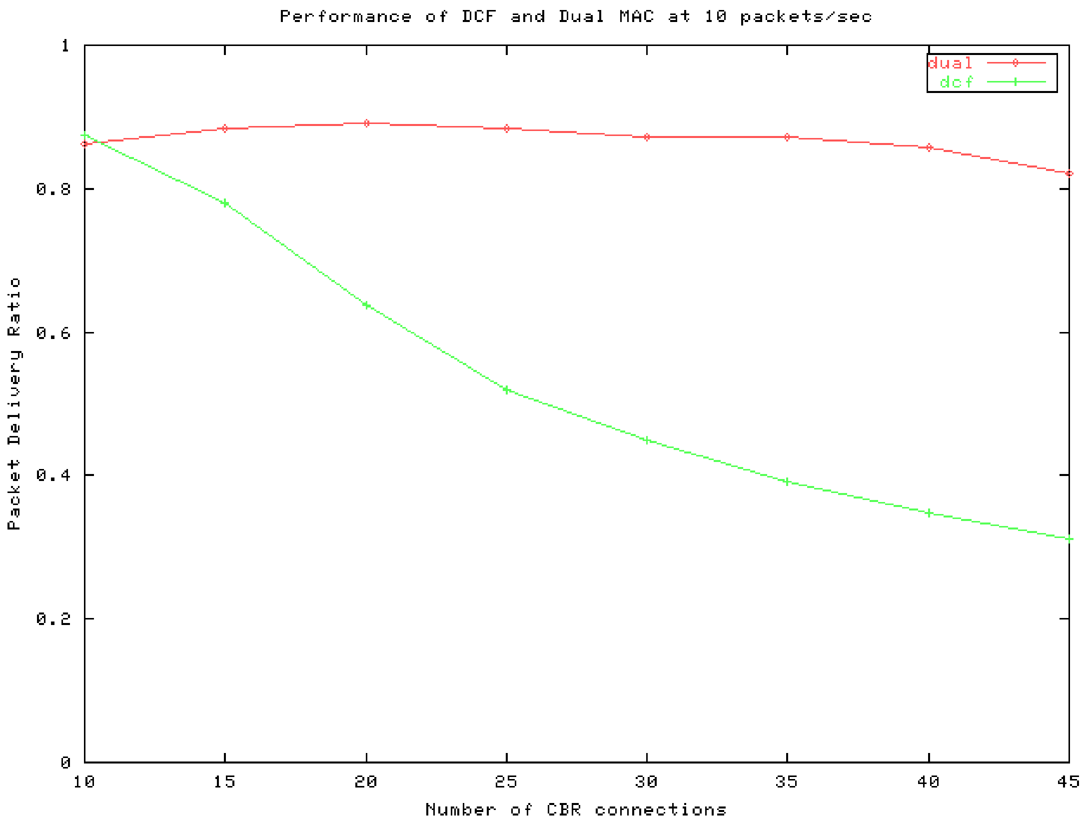

Figure 6.4: Dual MAC Vs DCF MAC at 10 packets/sec

The graphs for the “packet delivery ratio Vs number of connections” for different packet rates are shown in the Figures 6.4, 6.5, and 6.6. The x-axis indicates the number of CBR connections and the y-axis indicates the ratio of packets delivered to the destinations to the number of packets sent. The dual MAC offers substantially higher packet delivery ratio for all the cases. It should be noted that the traffic at 30 packets/second with more than 10 connections corresponds roughly to a load greater than 30x10x512x8 = 1228800 bites/sec (1.2Mbps). Even at this load the packet delivery ratio of dual MAC is nearly 84% as compared to DCF at approximately 50%. The Figure 6.7 shows the throughput of network with dual MAC and with PCF MAC. It can be clearly shown that at high loads the performance of dual MAC is substantially better than the DCF MAC.

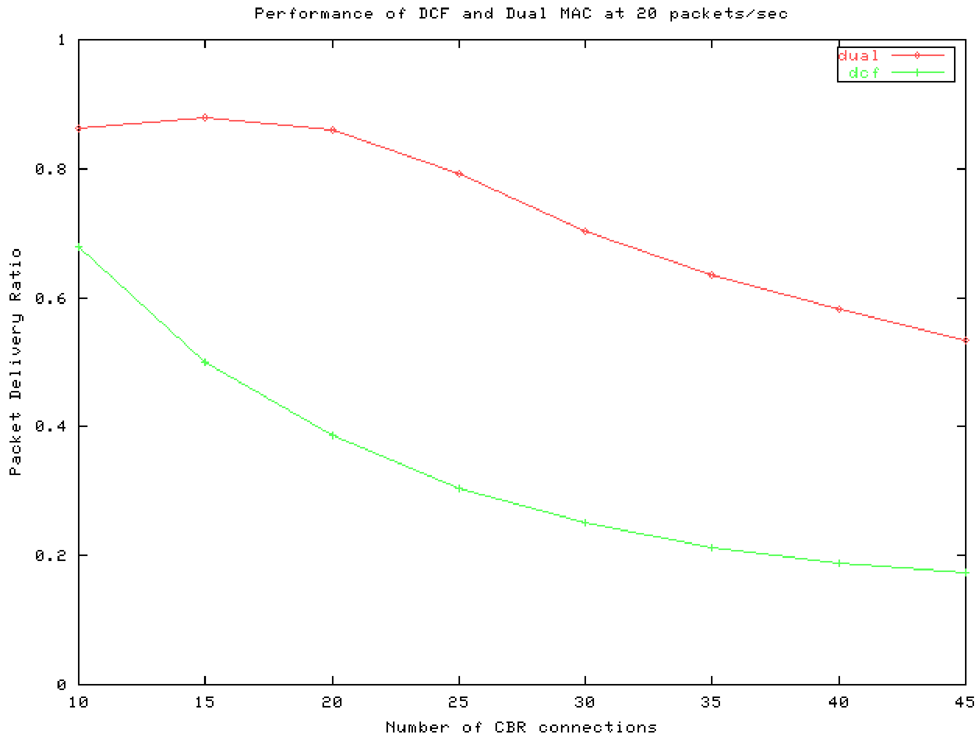

Figure 6.5: Dual MAC Vs DCF MAC at 20 packets/sec

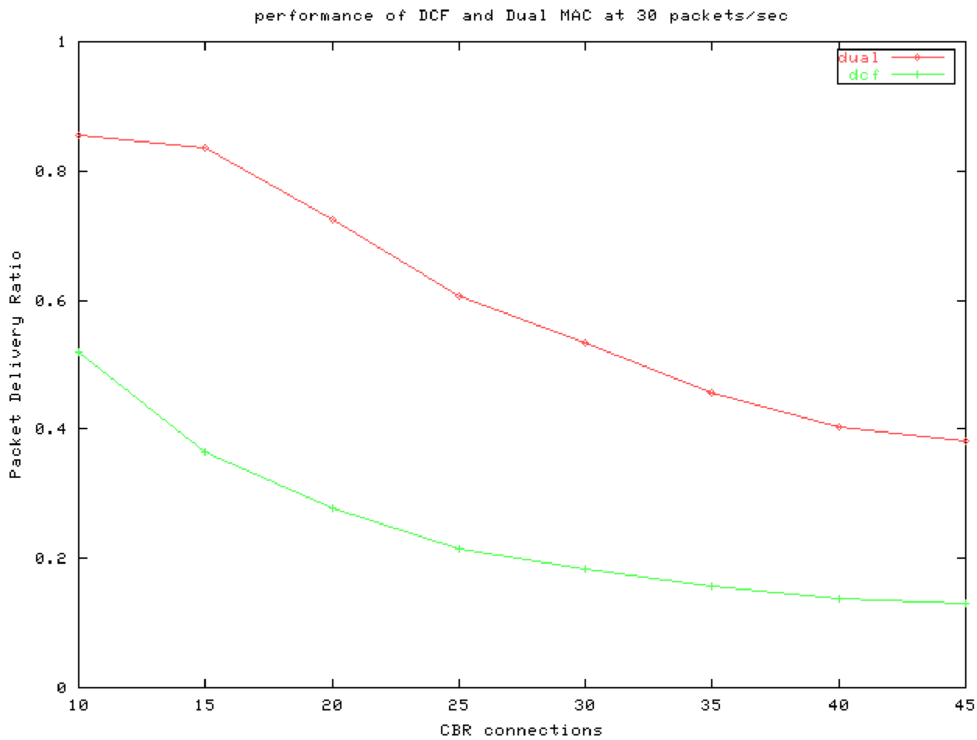

Figure 6.6: Dual MAC Vs DCF MAC at 30 packets/sec

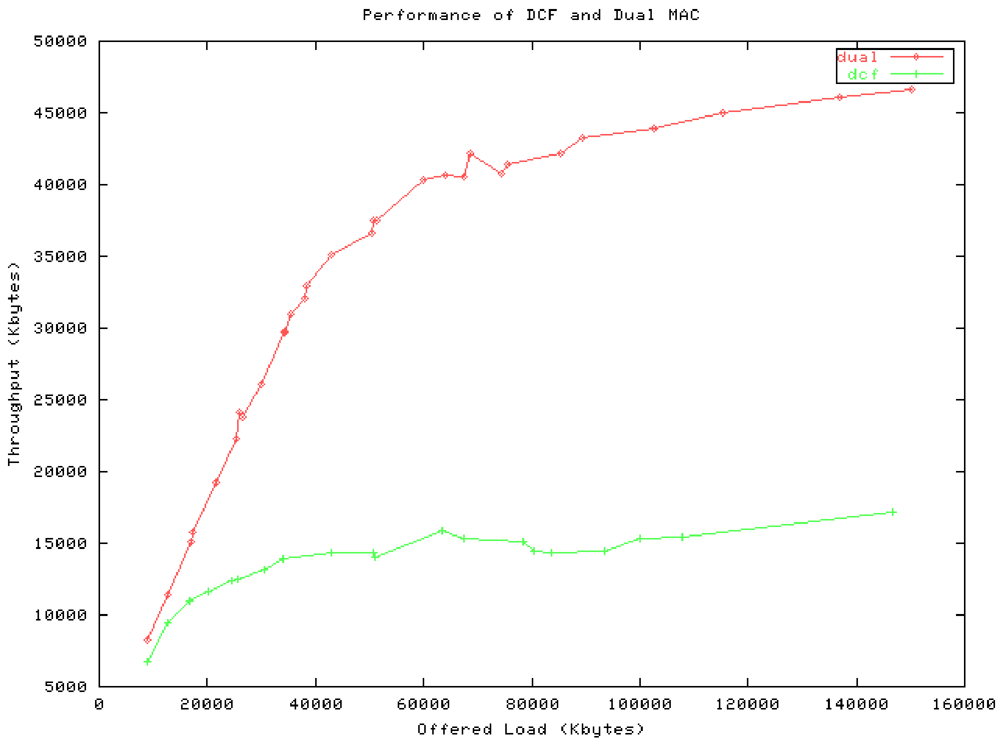

Figure 6.7: Dual MAC Vs DCF MAC - overall Throughput

6.4 Discussion on Results

As seen from the graphs in the Figure 6.7, the performance of dual MAC is considerably better than that of DCF MAC. The increase in the performance is attributed to following reasons:

- The PCF and DCF operate at different channels. This means that there is parallelism in the packet transmissions. This also eliminates the hidden node problem in the centralized scenario.
- The dual MAC offers parallelism by allowing the transmissions and receptions by DCF MAC even if the NAV of PCF MAC is set during the poll by PC. This eliminates the exposed node problem at boundary nodes which are exposed to the PC when the PC polls the stations.

We can see from the graphs that the throughput performance increase with dual MAC is more than twice that of DCF, which is remarkable considering that only few stations have dual MAC.

Chapter 7

Conclusion and Future Work

7.1 Conclusion

The design of a MAC that meets the demand of a multihop wireless network is great challenge. The restrictions like limited bandwidth, low power, and limited transmission range make this challenge even greater. Further, the hidden and exposed node problems offer even more difficulties by increasing the chance of collision. In this work, we have investigated the usefulness of IEEE 802.11 MAC protocol using the PCF and DCF mechanisms. We find that without modifications, the PCF and DCF are not very useful in multihop networks. We also find that the high traffic in the central region of a real-life centralized multihop network makes the DCF unsuitable. We investigated the use of PCF in central region to cope up the high traffic requirements in the central region. However, it gave rise to exposed and hidden node problems. The dual MAC was designed to eliminate exposed and hidden node problems in the central region of a centralized multihop network. The thesis discussed the design and architecture of dual MAC along with its implementation in NS.

The results show that the dual MAC performs reasonably better than the DCF access mechanism. However, the dual MAC requires two physical radios and two separate channels – one bound to PCF and another to DCF. We may however, note that the throughput gain is worth the cost of dual MACs since only few nodes need to be equipped with dual MAC.

The main focus of this thesis is to suggest a modification to the existing IEEE 802.11 MAC so as to make it suitable in multihop ad-hoc networks, especially in the real life centralized networks. The results presented in the thesis are applicable for static scenario, nevertheless, the dual MAC is expected to perform better even under mobile scenario. The effect of mobility on performance of dual MAC still remains to be seen.

One of the reasons we could not study the effect of mobility was lack of implementation of association and disassociation of stations to PC in PCF in NS. Lack of this feature restricted to allow stations to move and dynamically associate and disassociate from the PC.

7.2 Related Work

The dual MAC aims at eliminating the exposed and hidden node problems at the center of the topology where PCF is used. Very little work has been done on centralized topologies, and using PCF in an ad-hoc networks. Most of the previous work has been concentrated on DCF mode of 802.11. Poojary, Krishnamurthy and Dao [10] have tried changing power of control packets (RTS, CTS and ACK) with stations having power control capabilities. They show that it does not increase the throughput of the network due to overheads. Deng and Haas propose dual Busy Tone Multiple Access (DBTMA) [11] for eliminating the exposed and hidden node problems. DBTMA used different channels for data and control packets. Nasipuri and Das [12], [13] have proposed MAC with multiple channels, and shown throughput improvement.

The dual MAC has been designed keeping in the mind the number of channels available in 802.11. The most common method of physical access in available WLAN cards is the DS-CDMA. The 802.11 with DS-CDMA allows three different channels. The dual MAC can use any two of them. Another advantage of using dual MAC is that very few stations need the dual MAC capability (Boundary Nodes) and rest of the stations can continue using existing WLAN cards. However, the dual MAC requires that PCF and DCF be done at different frequencies.

7.3 Future Work

One very useful extension to this work will be a scenario where one of the stations automatically becomes the PC after seeing high traffic in its vicinity. This requires a mechanism for a node to become PC and inform other station about the same. This will mean that the high traffic regions perform scheduled MAC, i.e., the PCF, and the surrounding stations use the DCF. In this scenario, the dual nodes promise to be of great use by providing parallelism at the boundary stations. The dual MAC can also be enhanced to use both the MACs in DCF and/or PCF mode, even if the station is in a region where only PCF or DCF is being used. (Currently only possible operation is that of one of MACs using the DCF and another using the PCF at boundary stations.) This enhancement will mean that the parallelism offered by two channels will increase the throughput considerably.

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