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ABSTRACT

SERVICE DIFFERENTIATION IN MULTIHOP WIRELESS PACKET NETWORKS

by
Ilker Onat

This work explores the potential of link layer scheduling combined with MAC layer prioritization for providing service differentiation in multihop wireless packet networks. As a result of limited power, multihop characteristic and mobility, packet loss ratio in wireless ad hoc networks tends to be high compared to wireline and one-hop mobile data networks. Therefore, for wireless ad hoc networks, DiffServ-like distributed service differentiation schemes are more viable than hard QoS solutions, which are mainly designed for wireline networks. The choice and implementation of proper queuing and scheduling methods, which determine how packets will use the channel when bandwidth becomes available, contributes significantly to this differentiation. Due to the broadcast nature of wireless communication, media access is one of the main resources that needs to be shared among different flows. Thus, one can design and implement algorithms also at MAC level for service differentiation. In this study, in addition to the scheduling discipline, IEEE 802.11 Distributed Coordination Function is used to increase the media access probability of a specific class of traffic. It is shown that the service requirements of a class can be better met using this two level approach compared to the cases where either of these schemes used alone.

SERVICE DIFFERENTIATION IN MULTIHOP WIRELESS PACKET NETWORKS

by
Ilker Onat

A Thesis
Submitted to the Faculty of
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Department of Electrical and Computer Engineering

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APPROVAL PAGE

SERVICE DIFFERENTIATION IN MULTIHOP WIRELESS PACKET NETWORKS

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To my beloved family

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CHAPTER 1

INTRODUCTION

Quality of Service (QoS) is defined as a set of service requirements that needs to be met by the networks while transporting a flow [1]. Although QoS provisioning has been well studied and implemented in wireline networks, it is less explored in wireless domain. Recently, several efforts have been devoted and some solutions have been proposed for offering QoS services in one-hop mobile wireless data networks. However, ad hoc wireless networks pose additional challenges due to the lack of an infrastructure which means lack of a fast, wired backbone network. In addition,

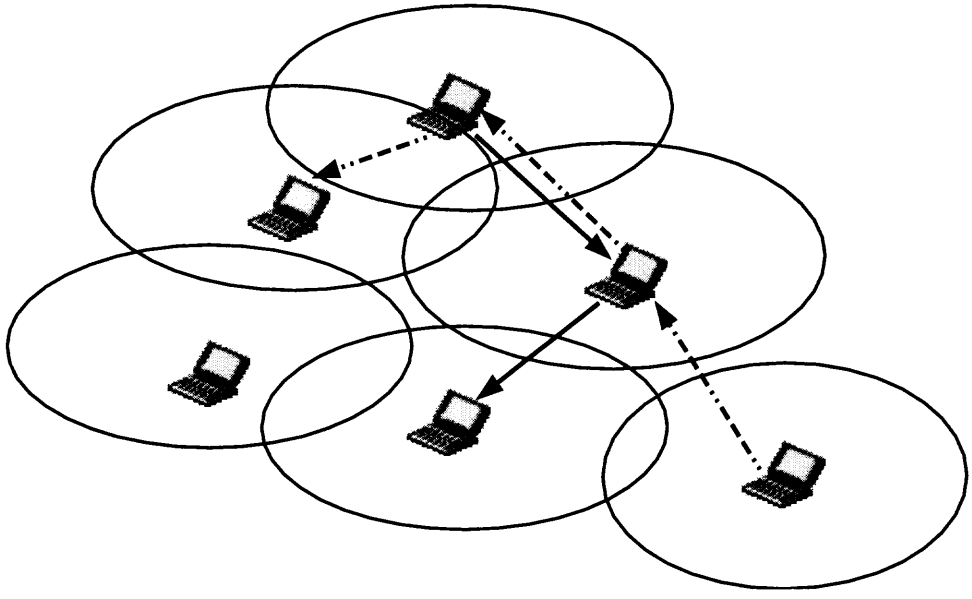


Figure 1.1 A wireless ad hoc network.

in wireless ad hoc networks all the hosts are routers which transmit each others packets in a multihop fashion as illustrated in Figure 1.1. Hard QoS solutions mainly designed for wireline networks are more difficult to adopt in this power limited, mobile and multihop environment where the contention for bandwidth is higher. Therefore,

DiffServ-like packet differentiation schemes seem to be the more viable and robust QoS solutions for wireless ad hoc networks.

Achieving packet level service differentiation can be done at different layers. The experience from wireline QoS [2] indicates that the choice of proper queuing and scheduling methods at the network layer, which determine how packets use the channel when bandwidth becomes available, contributes significantly to the service differentiation. In addition to the queueing and scheduling disciplines, the medium access rights at the Medium Access Control (MAC) sublayer can also be used to grant higher access probabilities to mobiles having high priority traffic.

In this thesis, a combined distributed multilayer approach is proposed which uses both link layer priority scheduling and 802.11 Distributed Coordination Function (DCF) [3] prioritization. The network performance metrics used are the average delay and total throughput which are evaluated separately for the high and low priority traffic classes. It is shown that statistical service differentiation can be better achieved using proper queueing and scheduling techniques combined with the 802.11 DCF support. With this twofold scheme, schedulers at each individual mobile push high priority traffic first. At the MAC level, modified 802.11 DCF ensures that those mobiles having high priority traffic are more likely to acquire the channel. Then, it is demonstrated that this approach outperforms either scheme used alone. Namely, with this scheme, high priority delay sensitive traffic class has lower average delay and higher throughput figures while low priority best effort class retains almost the pre-prioritization level results with slight degradations.

The rest of the thesis is organized as follows. Chapter 2 describes the related work. Chapter 3 gives a summary of differentiated services framework along with implementation difficulties of DiffServ in wireless ad hoc networks. Chapter 4 describes the Ad hoc On demand Distance Vector (AODV) [4] routing protocol and link layer interface queue implementation. A summary of IEEE 802.11 protocol, its MAC DCF

internals and DCF's use in service differentiation is given in Chapter 5. Chapter 6 details the Network Simulator (ns-2) [5] and simulation model used throughout this thesis. Finally, in Chapter 7, the performance evaluation and corresponding results are presented.

CHAPTER 2

RELATED WORK

Priority scheduling is defined as the type of scheduling where different classes of packets are given different priorities. For instance, in ad hoc networks, routing control packets are given higher priority over data packets. The effects of link layer scheduling algorithms on the system performance of mobile ad hoc networks is analyzed in [6]. In [6], it is shown that average delay and throughput of a wireless ad hoc network may be improved with proper scheduling techniques. Authors in [6], use control and constant bit rate (CBR) data packets as the two basic classes of traffic. First, the benefit of a conventional priority scheduler is observed as the reduction of the average delay by 40%. Later, network load and mobility patterns are changed and various scheduling algorithms (like shortest-path-length-first, fewest-remaining-hops-first, round robin and greedy scheduling) are tested. Network performance is expressed as the average packet delay and overall throughput. However, improving the average system performance does not necessarily improve the service given to a specific class because of distinct application requirements. In many cases, lower average delay and higher average throughput might be achieved at the expense of starving flows. In addition, these two basic performance parameters are highly susceptible to the mobility and flow constructions – in this thesis study, it is observed that backlogged flows passing through small number of hops bring about exceptionally high throughput values. Queueing and scheduling techniques must not only maximize *utilization*, but also increase the fairness of the system and take into account application level service requirements.

A core-extraction distributed ad hoc routing algorithm (CEDAR) is proposed in [7]. Three key components of CEDAR are the establishment and maintenance of

a self-organizing routing infrastructure called *core* to perform route computations, the propagation of link state information and a QoS route computation algorithm executed at the core nodes using locally available state.

Authors in [8] propose using probe messages from source to destinations for a low-cost path that satisfies the QoS requirement of the flow. In this scheme, permission to search a path is given by a ticket scheme where tickets are produced by the source nodes depending on the available state information.

Distributed control is another mainstream method for service differentiation in wireless ad hoc networks. [9], [10], [11], [12] and [13] propose achieving service differentiation by managing the media access chances of hosts depending on the packet types they are trying to send with modifications to IEEE 802.11 DCF.

In addition to IEEE 802.11 DCF modification to support service differentiation, authors in [9] propose a monitoring algorithm to estimate achievable service quality that is used for the admission control of high priority traffic. Using these two schemes, high priority packets are given statistically lower delay and loss figures compared to the low priority best-effort traffic. In [9] it is recognized that their approach can only provide softer assurances in comparison to more tightly coupled control systems. However this kind of a distributed scheme is more scalable and more flexible in delivering diverse application requirements. Solutions providing fairness at the MAC layer of wireless packet networks are proposed in [14] and [15]. Both papers achieve throughput fairness with distributed control but do not deal with service differentiation.

Task group E of the IEEE 802.11 working group is currently working on an extension to IEEE 802.11 called IEEE 802.11e. The IEEE 802.11e introduces a new access mechanism called Enhanced DCF (EDCF) that brings service differentiation improvements – like different contention window and interframe space assignments for

different priority classes – over regular 802.11 DCF which uses Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA).

CHAPTER 3

DIFFSERV AND WIRELESS MULTIHOP NETWORKS

3.1 An Overview of Differentiated Services Framework

Differentiated Services (DiffServ or DS) framework [2] is introduced to cope with the scalability problems of Integrated Services (IntServ) [16]. In the latter, service is provided to each individual data flow, which requires routers to keep the state of each flow using Resource Reservation Protocol (RSVP) [17]. In heavily loaded backbone routers, keeping the state of each flow is a burden that decreases the performance of the overall network.

DiffServ architecture includes a set of per-hop forwarding behaviors, packet classification and traffic conditioning functions including metering, marking, shaping and policing (Figure 3.1).

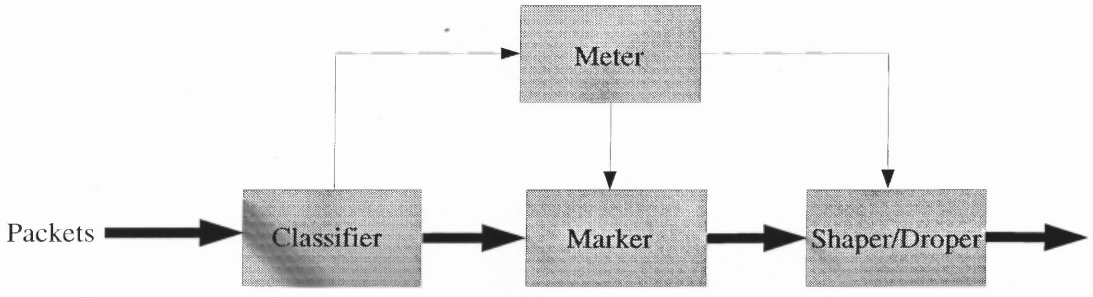


Figure 3.1 Logical view of a Packet Classifier and Traffic Conditioner.

Scalability is achieved by implementing classification and conditioning functions only at network boundary nodes, and by applying per-hop behaviors (PHB) to aggregates of traffic which have been marked using the DS field in the IPv4 or IPv6 headers [18] as illustrated in Figure 3.2.

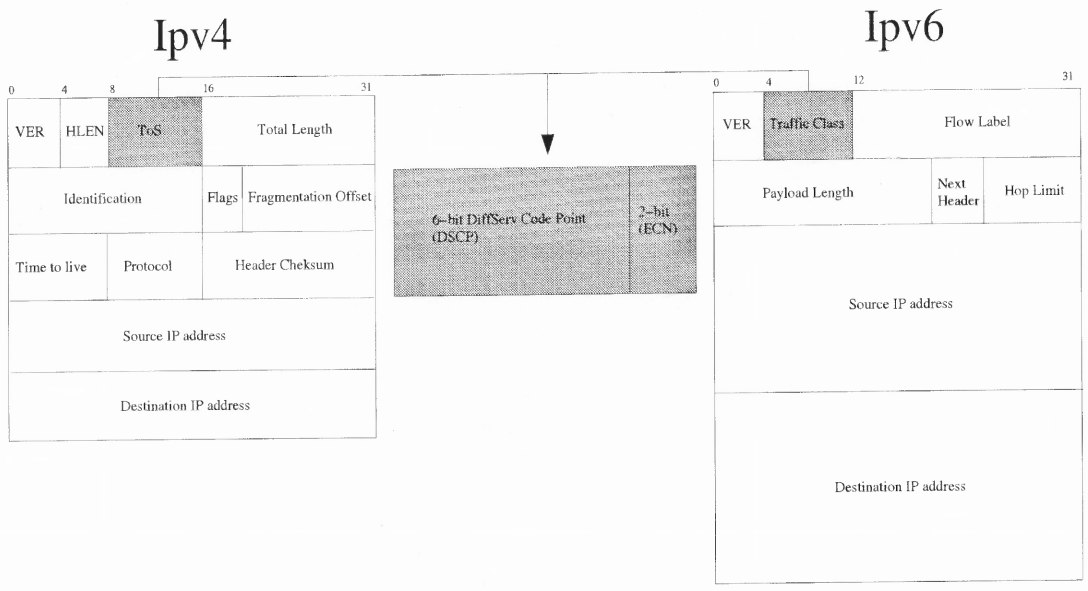


Figure 3.2 IPv4 and IPv6 DiffServ octets.

3.1.1 Basic DiffServ Terminology

Behavior Aggregate (BA): a DS behavior aggregate.

BA classifier: a classifier that selects packets based only on the contents of the DS field.

Classifier: an entity which selects packets based on the content of packet headers according to defined rules.

DS behavior aggregate: a collection of packets with the same DS codepoint crossing a link in a particular direction.

DS codepoint: a specific value of the DSCP portion of the DS field, used to select a PHB.

DS domain: a contiguous set of nodes which operate with a common set of service provisioning policies and PHB definitions. An illustration of a DiffServ domain is given in Figure 3.3.

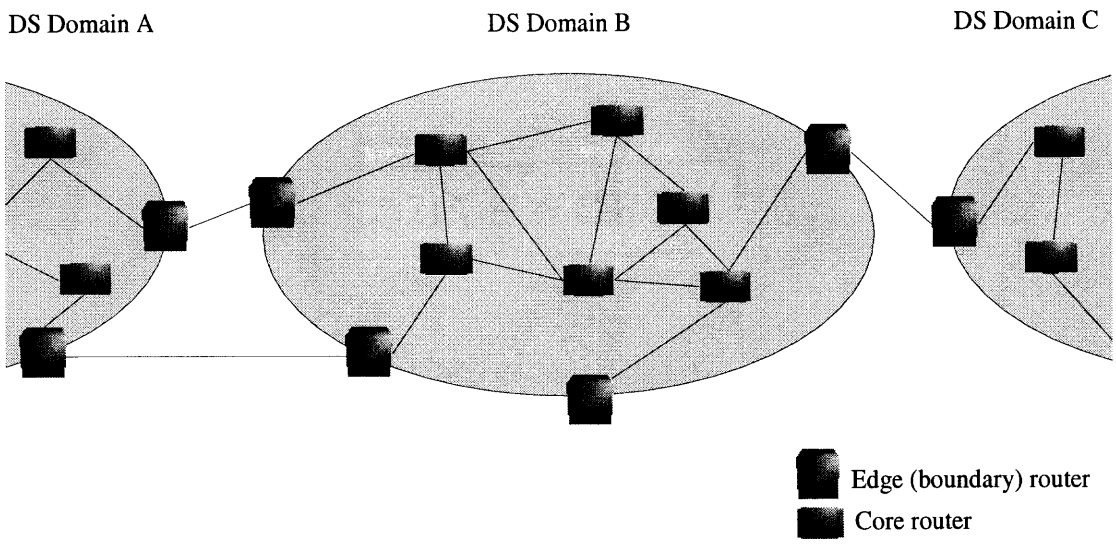


Figure 3.3 DiffServ Domain.

DS edge node (boundary node): a DS node that connects one DS domain to a node either in another DS domain or in a domain that is not DS-capable. Edge routers perform sophisticated, time consuming and processor intensive jobs. A functional diagram of an edge router is given in Figure 3.4. Packets arriving at the boundary of a DiffServ domain either from a DS-compliant or non-DS domain, experience classification and traffic conditioning. Each packet is marked with a codepoint depending on the Service Level Agreements (SLAs). The marking process creates traffic aggregates which get distinct treatments inside the DiffServ domain.

DS field: the IPv4 header Type of Service (ToS) octet or the IPv6 Traffic Class octet. The six most significant bits of the DSCP field encode the DS codepoint.

Marking: the process of setting the DS codepoint in a packet based on defined rules.

Metering: the process of measuring the temporal properties (e.g., rate) of a traffic stream selected by a classifier. The instantaneous state of this process may be used

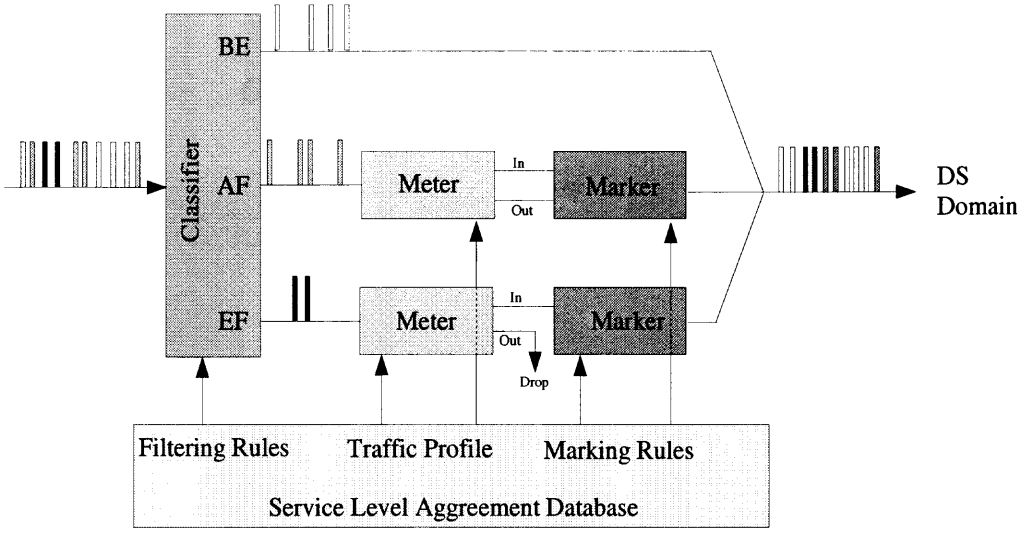


Figure 3.4 DiffServ Edge Router.

to affect the operation of a marker, shaper, or dropper, and/or may be used for accounting and measurement purposes.

Per-Hop-Behavior (PHB): the externally observable forwarding behavior applied at a DS-compliant node to a DS behavior aggregate.

Policing: the process of discarding packets (by a dropper) within a traffic stream in accordance with the state of a corresponding meter enforcing a traffic profile.

Service Level Agreement (SLA): a service contract between a customer and a service provider that specifies the forwarding service a customer should receive. A customer may be a user organization (source domain) or another DS domain (upstream domain). A SLA may include traffic conditioning rules which constitute a TCA in whole or in part.

Shaping: the process of delaying packets within a traffic stream to cause it to conform to some defined traffic profile.

Traffic conditioner: an entity which performs traffic conditioning functions and which may contain meters, markers, droppers, and shapers. Traffic conditioners are typically deployed in DS boundary nodes only. A traffic conditioner may re-mark a traffic stream or may discard or shape packets to alter the temporal characteristics of the stream and bring it into compliance with a traffic profile.

Traffic Conditioning Agreement (TCA): an agreement specifying classifier rules and any corresponding traffic profiles and metering, marking, discarding and/or shaping rules which are to apply to the traffic streams selected by the classifier. A TCA encompasses all of the traffic conditioning rules explicitly specified within a SLA along with all of the rules implicit from the relevant service requirements and/or from a DS domain's service provisioning policy [2].

3.1.2 Per-Hop Behavior

Per-Hop Behavior is the externally observable forwarding behavior applied at a DS-compliant node to a DS behavior aggregate [2]. DiffServ improves scalability by reducing the complexity and state information in routers. Packets are classified and marked at the entrance of a DiffServ domain by the edge routers using policers and shapers. Marking is done by assigning a DiffServ codepoint (DSCP). A codepoint corresponds to a particular per-hop behavior (PHB). Basically a PHB, consists of queueing and scheduling rules. There are three PHB's defined:

- **Expedited Forwarding (EF)** [19]: Provides guaranteed bandwidth, low delay and low loss. In order to provide EF PHB, the queues used by this aggregate should be almost empty all the time. This buffer occupation level can only be achieved by guaranteeing that maximum arrival rate of EF stream is less than its minimum departure rate. Proper admission control and policing techniques has to be used to shape the incoming traffic.

- **Assured Forwarding (AF)** [20]: It provides a base rate while permitting the use of any available capacity. Packets over the base rate are either marked best-effort or dropped. Because of the base capacity, the overall drop rate is lower than pure best-effort. It also allows small amounts of bursts pass through unharmed. Implementation has to assure that packets of a specific flow are not reordered.

- **Best-Effort Forwarding**: No guarantee is given. Incoming traffic is accepted without any shaping. When the network resources are unavailable, packets are dropped.

Core routers in the inner network need only forward aggregate streams according to their PHB's. The limited functionality here guarantees fast processing of packets in the inner heavily loaded core routers.

3.2 QoS and Mobile Ad Hoc Networks

To deploy evolving applications into wireless ad hoc networks, the QoS support has to be addressed in the wireless domain. However, as a result of the mobility, wireless channel impairments and limited power, the packet loss ratio in wireless networks are higher than wireline networks. Deterministic, hard QoS solutions which require complex signaling overhead which is again subject to higher losses are difficult to implement in wireless networks. Different from the one-hop mobile networks, mobile ad hoc networks have additional multihop and router/host indistinction complexities, bringing added pressure on individual hosts by constraining their power consumption. Moreover, the overhead of hard* QoS routing in an ad hoc network is likely to be

*The terms *hard* and *soft* guarantees are not well-defined precise definitions in the literature. Most of the time, hard guarantees are meant to define flow based resource reservations using RSVP. Soft guarantees are used to describe DiffServ-like statistical service differentiation. However, the term *soft* is also used in RSVP-like schemes where there may exist transient time periods when the required QoS is not guaranteed due to path breaking

higher than that in a wireline network because the available state information is less precise, and the topology changes in an abrupt and unpredictable way. Under these circumstances, DiffServ-like packet differentiation schemes can be more preferable to the solutions requiring complex RSVP signaling.

The lack of a fixed base backbone network and the lack of distinction between routers make direct application of traditional DiffServ concepts to wireless ad hoc networks very difficult. DiffServ ideas have been introduced to address the QoS needs of fixed wireline networks. Adapting DiffServ to mobile ad hoc networks requires some deviation from the original implementations. A DiffServ domain is a vague term for ad hoc networks. Even after the assumption that some kind of a clustering is possible, we are left with the problem of defining edge and core routers. All the nodes which are at the same time routers are moving; there is no fixed entrance or exit nodes to mobile domains.

3.3 Packet Differentiation and Priorities

On the other hand, DiffServ-like relative differentiation schemes can be implemented in mobile ad hoc networks. Each mobile can be configured to treat certain packet types *better* than others. In addition, a mobile's right to access the shared medium can be made dependent on the packet type it is about to send.

Packet differentiation can be done in many ways. Users can be grouped and packets created by each group can be given different priorities. Packets can be prioritized based on the hop count they will travel or the ToS field can be used as in wireline DiffServ. Similar to the use of ToS, priorities can be assigned based on application requirements. Since application type, in general, represents what kind

---

or network partition. Likewise, in DiffServ some work refer to EF as *hard* guarantee in that with minor modifications (like peak rate host shaping, limiting the maximum packet size and dimensioning buffer and bandwidth) it can effectively bound the delay experienced by the high-priority traffic class.

of service the packet should get, it provides a reasonable way of packet classification for DiffServ implementations. For the best-effort traffic, the achievable throughput is a more important figure than delay. In this work, our objective is to minimize the delay of the delay sensitive CBR packets by giving them higher priority over best-effort TCP traffic. Under this scenario, quality will only be probabilistically guaranteed for different service classes.

CHAPTER 4

SCHEDULING AT THE INTERFACE QUEUE

Throughout this study, Ad hoc On demand Distance Vector (AODV) routing [4] is used as the underlying routing protocol. AODV is one of the most commonly used routing protocols in ad hoc networks. As the name *on demand* implies, it finds routes when requested. Another very commonly used on-demand routing protocol for ad hoc networks is Dynamic Source Routing (DSR) [21]. DSR is a source routing protocol in which data packets carry the entire path they are bound to follow. A performance comparison of this two routing protocols done in [22] reveals that for the networks with small number of nodes and with lower mobility DSR outperforms AODV both in average delay and packet delivery ratio. However, when the number of nodes and the average node speed are increased, AODV accomplishes better results though it incurs a higher routing overhead.

Packets waiting for a route in AODV are stored in a send buffer. The send buffer is a dropfront first-in first-out (FIFO) queue with a maximum waiting time. The interface buffer is between link and MAC layers. Packets passed by link layer are queued at the interface buffer until MAC layer can transmit them. Ns-2 [5] is used for modeling and simulations. The original implementation of this buffer in ns-2 is a priority queue that gives AODV routing control packets higher priority. Different scheduling algorithms are applied at this interface buffer. In a similar study [6] the effects of different scheduling algorithms on the performance of the overall system are tested using DSR as the routing protocol. The interface queue implementation of DSR in ns-2 is different from that of AODV. AODV interface queue maintains one physical queue while giving priority to control packets. The interface queue in DSR on the other hand maintains separate physical queues for different priority levels. In

this thesis study, the AODV interface queue implementation of ns-2 is modified and different scheduling algorithms are applied there.

4.1 Routing Protocol Description

In AODV routes are built when desired by the source nodes. Different from source routing algorithms, AODV uses an hop-by-hop routing mechanism; it only keeps track of next hop for a route instead of the entire route. It requires the flooding of route request (RREQ) packets until the packet reaches the destination. Any duplicate request packet received by the nodes are discarded. Once the request packet reaches an intermediate node which has a path to the destination (or the destination itself), a route reply (RREP) packet is sent as a unicast route reply packet informing the existence of the path. All routing messages carry sequence numbers, which, each node maintains about other nodes – destinations – in order to check the relative freshness of two pieces of routing information for the same destination. A node uses a routing message if the message has a greater sequence number or same sequence number but smaller hop count, thereby guarantees loop freedom. A route will continue to be maintained as long as it is active. A route is considered as active if there are data packets periodically traveling from the source to the destination along that route. Once data packets stop traveling a link, the intermediate node routing table entries used to maintain that route will time out and deleted from the routing tables. If a link break occurs while the route is active, the node upstream of the break propagates a route error (RERR) message to the source node to inform it of the now unreachable destination(s). After receiving the RERR, if the source node still desires the route, it can reinitiate route discovery. AODV is capable of both unicast and multicast routing. It is loop-free, self-starting and scales to large numbers of mobile nodes.

4.2 Priority Queueing

In this thesis interface queue of each AODV agent is modeled as multiple FIFO droptail queues where each queue is dedicated to a single priority. Higher priority queues are served – emptied – as long as they have packets to send Figure 4.1.

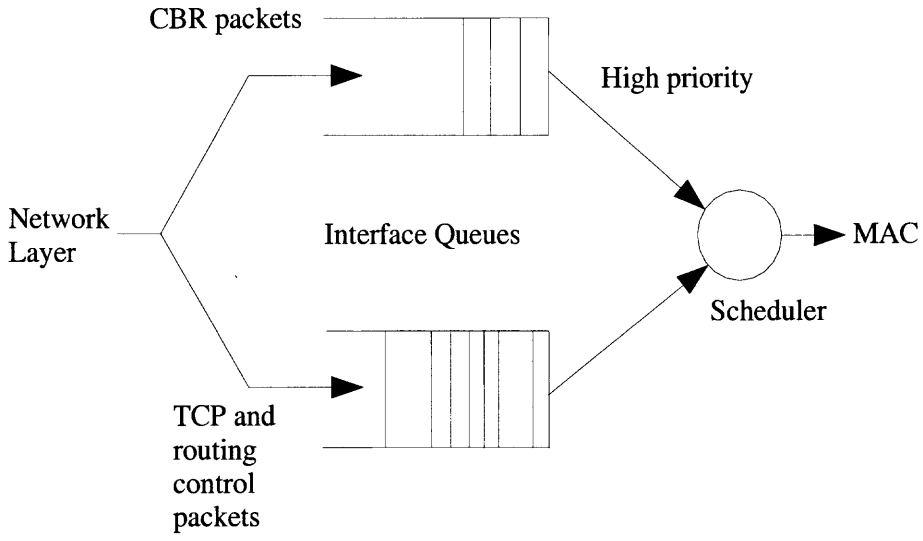


Figure 4.1 Scheduling CBR packets first at the interface queue.

In a priority queueing system, a packet in the highest priority queue will experience a calculated delay which is proportional to the data remaining to be serialized and the number of packets already queued in the specific queue the packet belongs to [23]. A priority queue limits the delay and variations in delay and can be used for flows having such requirements.

CHAPTER 5

IEEE 802.11 MAC PROTOCOL

The IEEE 802.11 [3] is currently the most commonly used wireless LAN standard which specifies a single MAC sublayer and 3 Physical Layer Specifications.

Stations can operate in two configurations:

1. **Independent (Ad hoc) Configuration**: The stations communicate directly to each other, no infrastructure needs to be installed. That is why this type of configuration is called an *ad hoc network*. Hosts in this mode operate as routers in that they relay other hosts' packets. Stations in such configuration are in a Basic Service Set (BSS).

2. **Infrastructure configuration**: The stations communicate to access points which are part of a distribution system. An access point serves the stations in a BSS. The set of BSSs are called Extended Service Set (ESS). 802.11 only specifies the air-interface, that is the interface between stations and between stations and access points.

The standard provides the above mentioned services with the following functionality:

- Roaming within an ESS
- Multiple data rates in BSSs
- Power Management: Stations can switch off their transceivers to conserve power.

The MAC protocol is Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA). In this protocol, when a node receives a packet to be transmitted, it first listens to ensure no other node is transmitting. If the channel is clear, it transmits the packet. If the station senses the medium as busy, it chooses a random *backoff*

time which is the time the node must wait until it is allowed to transmit its packet. The transmitter decrements its backoff counter when the channel is sensed as idle. If channel is busy the backoff counter is not decremented. When the backoff counter reaches zero, the node transmits the packet. Random backoff timers decrease the probability of collision. Collision detection, as employed in Ethernet Carrier Sense Multiple Access with Collision Detection (CSMA/CD), cannot be used for the wireless transmissions. When a node is transmitting, it cannot hear other nodes in the system since its own high power transmission signal will make other signals imperceptible.

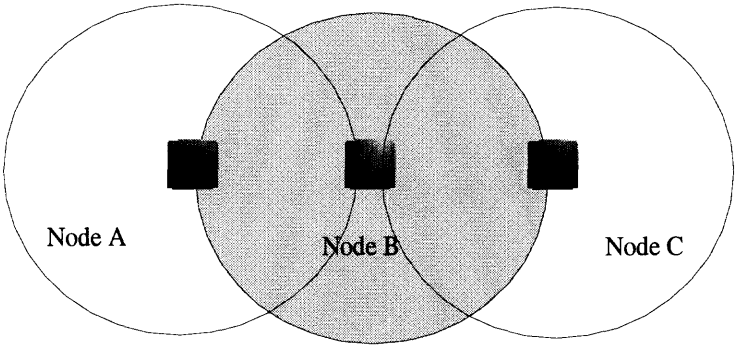


Figure 5.1 Hidden Node Problem.

When a packet is to be transmitted, the transmitting node first broadcasts ready-to-send (RTS) packet containing the length of the packet. Receiving the RTS, the receiver responds with clear-to-send (CTS) packet. After this exchange, the transmitting node sends its packet. If the packet is received successfully, the receiving node transmits an acknowledgment (ACK) packet. This exchange is necessary to avoid the *hidden node problem*, depicted in Figure 5.1. For instance in the arrangement of this figure, node A can hear node B, and node B can hear node C. However, node A cannot communicate with node C. Thus, although node A may sense the channel

to be clear, node C may in fact be transmitting to node B. The CTS broadcast of B silences node A for a predetermined duration until node C can transmit its packet.

The MAC layer defined by IEEE 802.11 standard is the lower part of the link layer and is placed between the dependent sublayer of the physical layer and Logical Link Control (LLC) sublayer of the link layer. The MAC architecture is composed by two basic coordination functions: the optional Point Coordination Function (PCF) and the mandatory Distributed Coordination Function (DCF). Each of these functions defines an operation mode for the stations that want to access the wireless medium. The Coordination Function determines which station will use the medium when it becomes available.

5.1 IEEE 802.11 Point Coordination Function

The PCF is introduced to bound the delay experienced by a station. It is useful for the transmission of time-sensitive information. With PCF, a point coordinator within the access point controls which station can transmit during any given period of time. The point coordinator steps through all stations operating in PCF mode and polls them one at a time. Each station in the polling list will thereby have a chance to send data within a given period. The synchronous and contention-free nature of PCF enables stations to transmit frames with regular time delays between transmissions. This makes it possible to more effectively support delay and jitter sensitive flows. However, in wireless ad hoc networks assumed to be consisting of all-mobile peer nodes, there is no access point which will coordinate the stations using PCF.

5.2 IEEE 802.11 Distributed Coordination Function

The DCF is the basic access mechanism of IEEE 802.11. It uses CSMA/CA. A station has to sense the channel as idle for a time interval greater than Distributed Interframe Space (DIFS) to transmit a frame. When a station cannot transmit because of DIFS, it defers the transmission as seen in Figure 5.2. The backoff time interval is a random value between 0 and Contention Window(CW) calculated as $T_{backoff} = Rand(0, CW) * T_{slot}$. The backoff timer initialized with the backoff interval is decreased every time medium sensed idle for a period longer than DIFS [3].

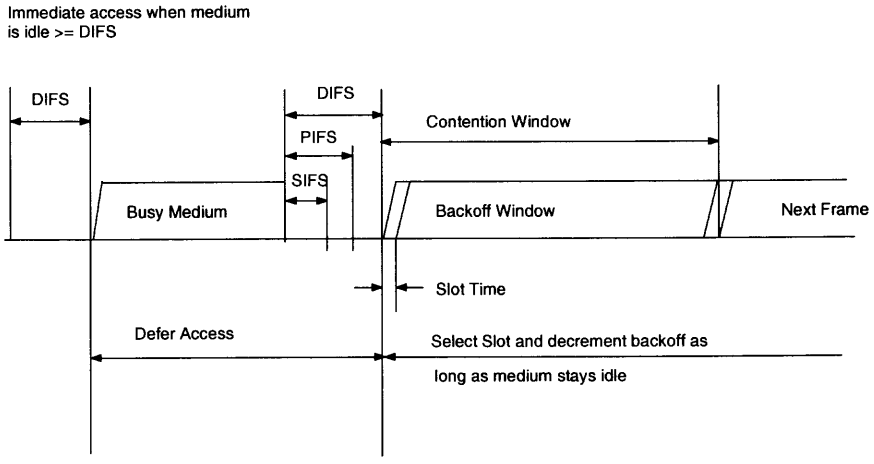


Figure 5.2 IEEE 802.11 DCF channel access.

When the backoff timer expires, the mobile transmits. If an acknowledgment is not received, the station assumes that the frame is lost, and reenters into backoff process. In order to decrease the collision probability, at each retransmit CW is doubled until a predefined CW_{max} is reached. CW is reset to CW_{min} after each successful transmission. Every frame waiting in station's buffer require a new backoff process.

If PCF is supported, PCF and DCF can coexist by dividing time into superframes. Each superframe has a contention free PCF duration and contention period where DCF is used.

5.2.1 802.11e EDCF: Enhanced Distributed Coordination Function

The extension to IEEE 802.11 called IEEE 802.11e aims at service differentiation by enhancing access mechanism of DCF. The new access mechanism is called Enhanced DCF (EDCF).

The EDCF combines two methods: CW_{min} and DIFS. The minimum contention window, CW_{min}, can be set differently for different priority classes. High priority classes can be given smaller CW_{min} that will increase the likelihood of channel being grabbed by one of them. Further differentiation can be similarly achieved by assigning different interframe spaces (DIFS) to different classes.

5.3 Service Differentiation using DCF Backoff Timers

Small CW_{min} values result in short backoff times which increases utilization and decreases average delay [9] with higher transmission attempt rates. However this also means a higher collision rate, higher drop rate and therefore lower throughput. These tradeoffs are reasonable for delay bounded better than best-effort services; It is preferable to drop a packet than to delay it excessively. Different CW_{min} values can be used to create different service classes. Among the different packets entering into backoff at the same time, the packet (the station with the packet) with the smaller CW_{min} is more likely to acquire the channel. Collisions increase CW for each packet with the same rate, which means a packet starting with a lower CW_{min} will always have advantage of having a smaller backoff time and therefore a higher probability of grabbing the channel [9].

CHAPTER 6

MODELING AND SIMULATION ENVIRONMENT

6.1 Network Simulator

Network Simulator second version (ns-2) is an object-oriented, discrete event driven IP network simulator written in C++, with an OTcl interpreter as a frontend. It implements a variety of network protocols, traffic source behaviors, queue management mechanisms and routing algorithms. The ns project is a part of the VINT project [5]. Along with the improvements to the simulator code, the group also works on visualization tools for simulation results, analyzers and converters that convert network topologies generated by well-known generators to ns formats.

6.1.1 Mobile Networking in Ns

The wireless model of ns is ported from CMU/Monarch group [24]. The wireless model essentially is made up of the MobileNode at the core, with additional supporting features that allow simulations of multihop ad hoc networks and wireless LANs. The MobileNode is a split object (C++/OTcl linkage). The C++ MobileNode is derived from parent Node. A MobileNode thus is the basic Node object with added functionalities of a wireless and mobile node like ability to move within a given topology, ability to receive and transmit signals to and from a wireless channel. A major difference between them, though, is that a MobileNode is not connected by means of Links to other nodes or MobileNodes.

The mobility features including node movement, periodic position updates and maintaining topology boundary are implemented in C++ while plumbing of network components within MobileNode itself (like classifiers, dmux , LL, MAC and Channel) have been implemented in OTcl. The schematic of a MobileNode is given in Figure 6.1 [5].

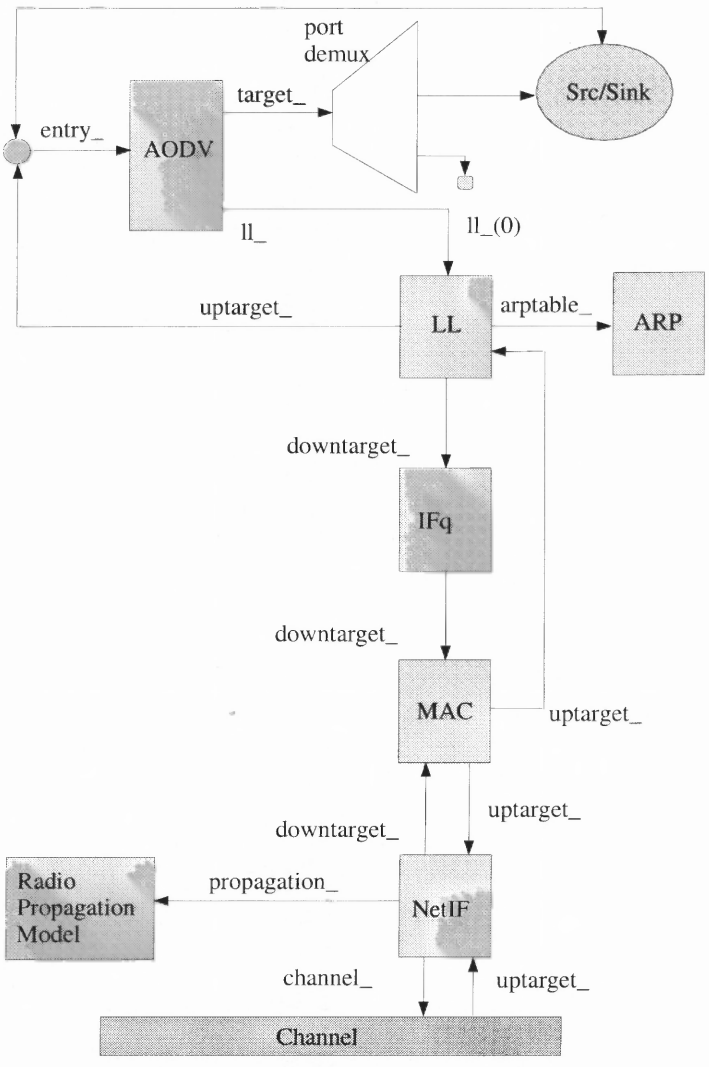


Figure 6.1 Schematic of a mobilenode under the CMU Monarch's wireless extensions to ns.

6.2 Simulation Model

An ad hoc network of 20 nodes where each node moves according to *random waypoint* mobility model in a grid of 700 x 700m is constructed. A node in the random waypoint model, moves to a random location with a random speed: Reaching that point it stops for a period of time and selects a new destination point and a new speed. The pause time is chosen as 2 seconds. The speed of mobile is a uniform random variable distributed between 0 and maximum speed. The maximum speed of a mobile is selected as 10 m/sec. 14 CBR and 21 TCP connections are created, all backlogged. All TCP connections were TCP-Tahoe with a conservative maximum congestion window size of 32 packets. Both CBR and TCP packet sizes are selected as 512 bytes with CBR rate of one packet per second. In this study, AODV interface queue implementation is modified so that each AODV agent is initialized with a separate queue for each priority level. Also, 802.11 MAC DCF implementation is modified for the purposes of this study.

CHAPTER 7

RESULTS AND DISCUSSIONS

Giving routing control packets higher priority over data packets decreases average delay of the network. However, for the differentiated services purposes, schemes giving control packets highest priority do not contribute positively to the delay reduction of a specific delay sensitive packet class. Especially at high mobilities where the control messages constitute a higher percentage of packets – because of higher number of link breaks, the mentioned negative effect of scheduling control packets first is more salient. While testing the prioritization schemes routing control packets are given the same priority as the best effort TCP traffic. A low CBR rate is used and CBR/TCP is kept at a ratio of about 1:6 to prevent the contention between CBR packets.

Both priority scheduling at the interface queue and MAC DCF priority schemes can be used to promote a specific class over best-effort traffic. In this study, the performances of CBR and best effort classes are compared under four different priority schemes:

- **No priority:** No priority given at any level.
- **Ifq priority:** CBR packets are dedicated a high priority buffer and scheduled first at the link layer interface queue.
- **MAC DCF priority:** CBR packets are given a CWMin value of 8 while all other packets use a CWMin of 32.
- **Ifq and MAC DCF priority:** Combined prioritization of CBR at both link layer interface queue and MAC level. CWMin values of MAC DCF are selected the same: 8 for CBR and 32 for the rest of the packets.

Figure 7.1 demonstrates the delay performance of CBR traffic under these priority schemes. It is clear that using this two layer combined approach has advantages over either scheme used alone in that with the combined approach, average delay experienced by a CBR packet decreases up to 35%. Furthermore, the aggregate throughput of high priority CBR class is higher when both schemes are used together as shown in Figure 7.2. In addition to that, as shown in Figure 7.3, best effort (TCP and routing messages) throughput is not significantly affected because of the priority schemes used.

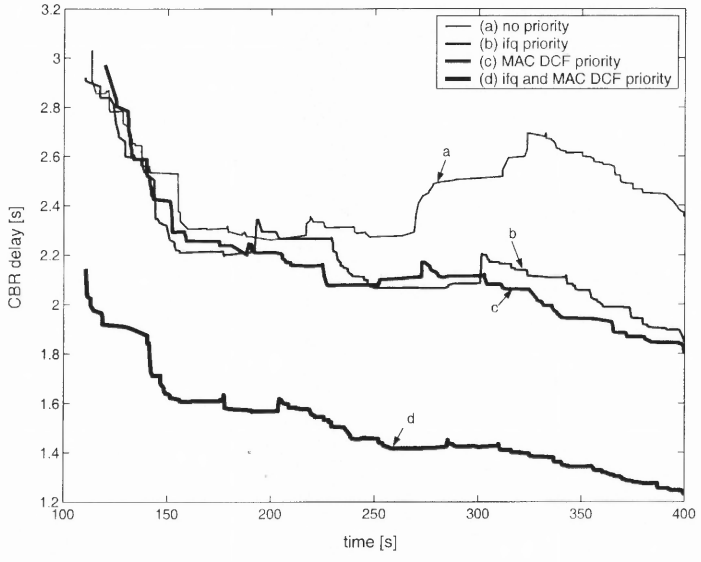


Figure 7.1 Average CBR packet delay vs. time, with CWMinCBR=8, CWMin=32.

7.1 Advantages of the Proposed Approach

At the link layer scheduler, there is not much one can do other then giving absolute priority to delay sensitive CBR data. However, one may consider getting similar improvements only with MAC DCF prioritization by increasing the difference between the CWMin values of high and low priority packets. Increasing the difference between the CWMin values interferes with the randomization property of 802.11 DCF. Namely,

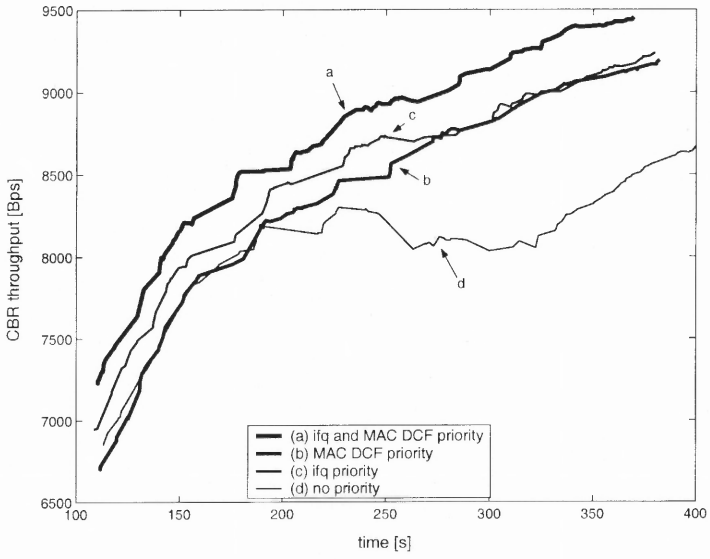


Figure 7.2 Aggregate CBR throughput vs. time, with CWMinCBR=8, CWMin=32.

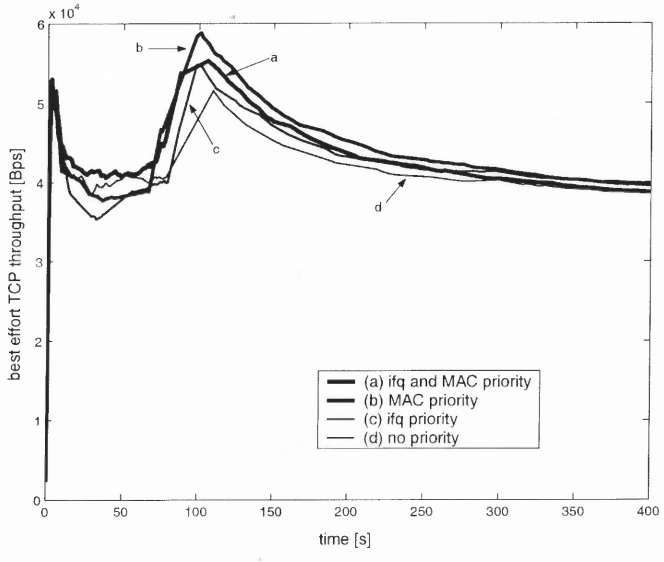


Figure 7.3 Aggregate TCP throughput vs. time, with ifq and MAC DCF priorities.

higher values of CWMin for low priority traffic does not significantly decrease the delay of high priority traffic as shown in Figure 7.4. The increased difference between CWMin values also causes unnecessarily long waiting times for low priority class which results in underutilization of the channel and higher average delay figures for the low priority as can be seen in Figure 7.5. On the other hand, interface queue prioritization of the high priority traffic does not interfere with the delay of the low priority traffic as shown in Figure 7.6.

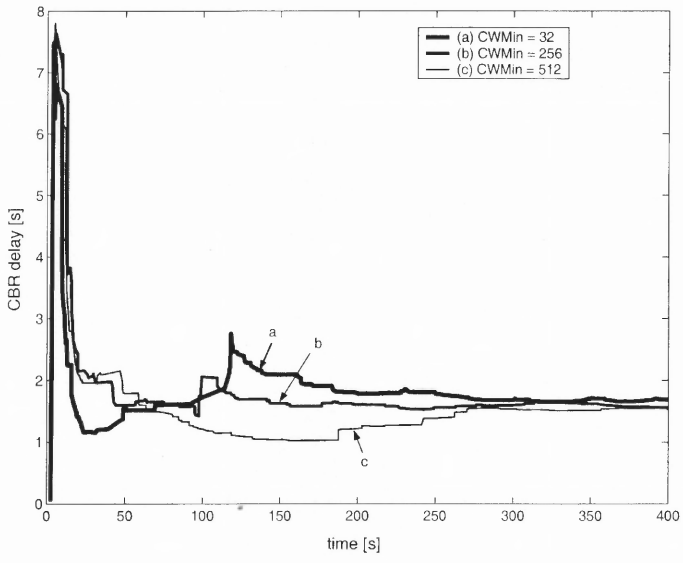


Figure 7.4 Average CBR packet delay vs. time, with increasing CWMin, CWMinCBR=8.

7.2 Conclusions and Future Work

In this thesis, an integrated approach for enhancing service differentiation in wireless ad hoc networks is proposed. A distributed scheme which uses both link layer priority scheduling and 802.11 DCF prioritization is introduced. It is shown that statistical service differentiation can be achieved using proper queueing and scheduling

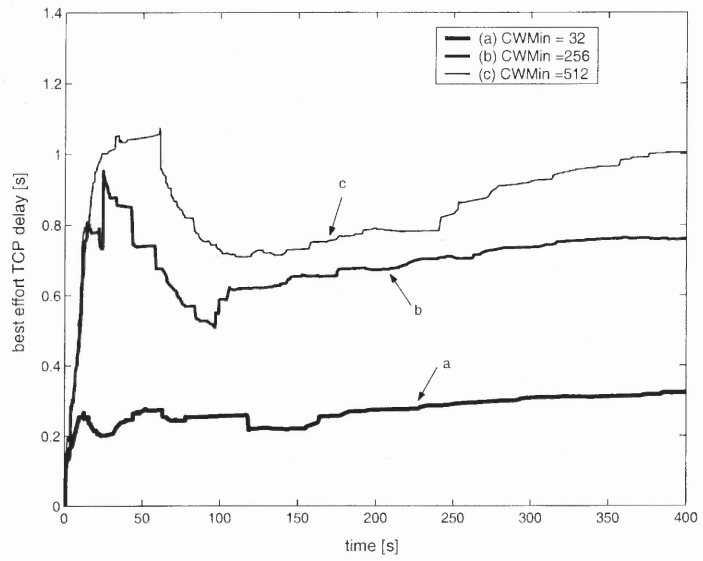


Figure 7.5 Average TCP packet delay vs. time, with increasing CWMin, CWMinCBR=8.

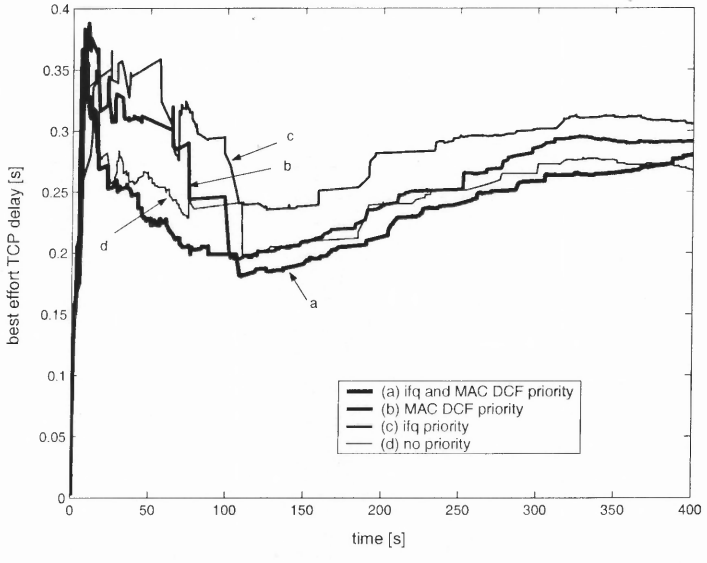


Figure 7.6 Average TCP packet delay vs. time, with ifq and MAC DCF priorities.

techniques combined with the 802.11 DCF support. It is also demonstrated that this approach outperforms either scheme used alone.

As a future work, it is planned to control best-effort traffic with Random Early Drop (RED) queueing at the interface queue. RED queueing is well studied for wireline DiffServ and proved to be a powerful tool for regulating data flows. The effectiveness of this method in wireless ad hoc environments will be investigated.

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