QUALITY OF SERVICE IN WIRELESS AD-HOC NETWORKS

by

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ABSTRACT

As a consequence of the increased popularity of wireless local area networks (WLANs) based on IEEE 802.11, the interest for ad hoc networks has also increased. An ad-hoc network is an autonomous wireless network that can be formed without the need of any infrastructure or centralized administration. It is composed of stations that communicate with each other through single-hop or multi-hop paths in a peer-to-peer fashion. One of the challenges that must be overcome to realize the practical benefits of ad hoc networks is Quality of Service (QoS).

Ad hoc networks have been proposed for a variety of applications where support for real time, multimedia services may be necessary. These proposed applications need Quality of Service guarantees in order to provide their services correctly. An important component for QoS provisioning is resource (bandwidth) estimation and admission control.

This thesis presents a strategy to provide flow-based Quality of Service on the top of MAC layer differentiated mechanisms in 802.11- ad-hoc wireless networks. We approach this by first evaluating 802.11 differentiation mechanisms and then present the strategy theoretically.

ACKNOWLEGEMENTS

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Thank you Lord Jesus Christ for been always there for me.

I dedicate this thesis to my parents and to my son Eliezer.

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CHAPTER 1. INTRODUCTION

1.1 Background

Mobile ad-hoc networks have captured the attention of many data networks researchers in the current decade or so. The Internet Engineering Task force (IETF) has crystallized the interest in mobile ad-hoc networks by forming a working group called MANET (Mobile Ad-hoc Networking). Since the MANET working group issued its charter [11] on January 1999, researchers have benefited from focusing on the challenges it defines.

The MANET charter views the ad-hoc network as a network that can be formed by group of mobile nodes that are able to operate as hosts and routers at the same time. Ad-hoc mobile nodes may submit, consume, or route the network traffic. The charter [11] also outlines the limited processing, and storage capabilities of mobile nodes, in addition it illustrates the difficulties introduced by various mobility scenarios and network dynamics. The MANET networking group has been focusing on solving the main challenges facing the deployment and commercialization of ad-hoc networks by specially defining a suitable set of routing algorithms.

Non-routing ad-hoc issues such Quality of Service (QoS), energy consumption, ad-hoc gateway design and discovery, ad-hoc IP auto-configuration and addressing schemes, and many other issues are not considered a core part of the MANET by definition. Thus research on area of QoS has evolved inconsistently and without a high level view of what an ad-hoc QoS should really mean and provide. The current QoS research efforts are a collection of independent research and some military projects.

The evolution of the multimedia technology and the commercial interest of companies to reach widely civilian applications made QoS in MANETs an area of great interest. This evolution calls for a complete solution for QoS in MANETs in order to provide effective communication of real-time traffic. With increase in multimedia applications, there is a need for wireless network to provide some QoS guarantees for highly sensitive application. These QoS guarantees can mainly be achieved through resource reservation and admission control.

Some aspect of providing QoS in MANET includes service differentiation in IEEE 802.11 (MAC QoS), Resource reservation, QoS aware routing and many others. In this thesis we shall focus on service differentiation in IEEE 802.11 and then propose a flow reservation strategy on top of differentiation services in the MAC layer.

1.2 Problem Description

Providing service differentiation in IEEE802.11 ad-hoc networks has been of a lot of interest in recent years. It's one of the aspects of providing QoS in wireless networks by mainly manipulating MAC layer parameters. It is a well known fact that most of these service differentiation mechanisms perform poorly as traffic increases in the network.

Actually, the common idea of differentiation mechanisms is to minimize packet transmission collision either by varying the contention window size for different traffic categories, or by employing appropriate backoff interval calculation methods to control the channel access of wireless stations. Under light or medium load, these mechanisms are efficient in the sense that all flows should backoff for a different period of time after collision and thus the likelihood of colliding again is rare. However, when the traffic load increases, without flow admission control, collision rate cannot be significantly reduced by only adjusting backoff intervals, i.e., collision rate increases with the increase of the traffic load. This increasing collision rate is very harmful for system performance and may yield low throughput and large packet delays. Therefore, in order to avoid the severe performance degradation under high traffic load, QoS flow reservation and admission control become critical.

1.3 Research Aim and Objective

The focus of this research is based on the flow reservation and admission control for quality of service (QoS) on IEEE 802.11 ad-hoc networks. The main aim is to provide per-flow QoS through reservation along the path that connects two mobile nodes. Hence provide better QoS guarantees for real-time applications on top of MAC IEEE 802.11 differentiation services.

Objectives include

1. evaluate the service differentiation techniques as an aspect of QoS in ad-hoc networks,
2. Propose a QoS flow reservation strategy that will help solve problems studied above.

1.4 Justification of project

Ad-Hoc Networks have limited wireless resources; time varying topology and lack of infrastructure. Theses factors make it difficult to provide QoS in MANETs.

The evolution of the multimedia technology and the commercial interest of companies to reach widely civilian applications made QoS in MANETs an area of great interest. This evolution calls for a complete solution for QoS in MANETs in order to provide effective communication of real-time traffic. With increase in multimedia applications, there is a need for wireless network to provide some QoS guarantees for highly sensitive application. These QoS guarantees can mainly be achieved through QoS reservation and admission control.

1.5 Overview of the thesis

The structure of the rest of the thesis will be as follows: In chapter 2 we review relevant literature and provide necessary background information for our project. Chapter 3 describes our approach and relevant tools used for the project. Chapter 4 describes our simulation results for the evaluation of differentiation mechanisms; it also provides our observation and analysis of the results. Chapter 5 describes our theoretically proposed QoS reservation strategy. Chapter 6 concludes the thesis and suggests future work. We have references which have been used right at the end of chapter 6 and we also have appendices which contain simulation scripts, description of how AODV works and how to insert an externally controlled variable in NS-2

1.6 Abbreviations

AODV	Ad-hoc On-demand Distance Vector
CBR	Constant Bit Rate
CEDAR	Core-Extraction Distributed Ad-Hoc Routing
CSMA/CA	Carrier Sense Multiple Access and Collision Avoidance
CTS	Clear To Send
DCF	Distributed Coordination Function
EDCF	Enhanced Distributed Coordination Function
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
MAC	Media Access Protocol
MANET	Mobile Ad-hoc NETworks
NS-2	Network Simulator Version 2
QoS	Quality of Service
RTS	Request To Send

CHAPTER 2. LITERATURE REVIEW

In this chapter we provide background on ad-hoc networks and review existing approaches in the provisioning of QoS in wireless ad-hoc networks. The existing approaches could be categorized into the following groups: MAC QoS, QoS-aware routing, inter-layer QoS model and QoS-aware application. We also look admission control and flow reservation in ad-hoc networks. We then conclude the chapter with a summary and thesis approach.

2.1 Mobile Ad-hoc Networks

A mobile ad-hoc network (MANET) is a wireless network temporarily and spontaneously created by mobile stations without requiring any infrastructure or central control. Network managements and communications are typically performed in a distributed manner. Though ad-hoc networks are treated with little difference in IEEE standards for wireless networks as a whole, some unique features make ad-hoc networks distinct from other types of wireless networks such as wireless LANs.

The first peculiarity is infrastructure-less, i.e. there is no pre-existing hardware like base stations in traditional cellular networks or any centralized mechanism managing the network. Ad-hoc networks are usually deployed in emergent and temporary situations such as accidents or public gatherings, where mobile stations may join the network at will, move around, or become disconnected at any time. Global synchronization is hard to achieve in such situations. And it is unrealistic to expect such a network to be fully connected, in which case a mobile station can communicate directly with every other nodes in the network via wireless channels (see Figure 1). As a result, the second important feature emerges - multihop communication. Each node in the network has to take the responsibility of relaying packets for its peers and a packet may traverse multiple nodes before it reach the destination.

Ad-hoc networks also are capable of handling topology changes and malfunctions in nodes. It is fixed through network configurations. For instance, if a node leaves the network and causes link breakage, affected nodes can easily request new routes and the problem will be solved.

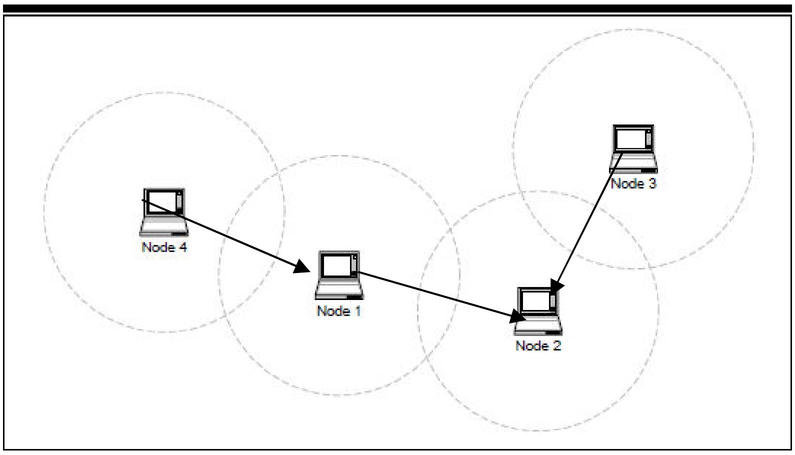

Figure 1 : Example of a MANET

2.2 Quality of Service (QoS)

In the fields of packet-switched networks and computer networking the traffic engineering term Quality of Service (QoS) refers to the probability of the network meeting a given traffic contract, or in many cases is used informally to refer to the probability of a packet passing between two points in the network.

QoS is also usually defined as a set of service requirements that needs to be met by the network while transporting a packet stream from a source to its destination [27]. The network needs are governed by the service requirements of end user applications. The network is expected to guarantee a set of measurable pre-specified service attributes to the users in terms of end-to-end performance, such as delay, bandwidth, probability of packet loss, delay variance (jitter), etc. Power consumption is another QoS attribute that is more specific to MANETs.

2.2.1 QoS metrics

QoS metrics are base parameters of quality for a network. QoS parameters include bandwidth, delay, jitter, security, network availability, and battery life and packet loss. The QoS metrics could be defined in terms of one the parameters or set of parameters in varied proportions.

The important QoS metrics for multimedia applications are delay, jitter, loss, and throughput. End-to-end delay is the time between the arrival of a packet and its successful delivery to the receiver. Another metric, access delay, is the time between packet arrival and packet transmission by the sender. Jitter is the variation of delay and is an important metric for multimedia applications. Finally, bandwidth is the measure of data transmission capacity and influences throughput, which is the amount of data successfully transmitted and received in unit time. Note that some of the data is lost in transit, and reducing the loss rate is an important QoS goal as well. In our work we focus on bandwidth as the QoS metric.

The QoS metrics could be concave or additive. [9] gives the definition of concave and additive QoS metrics: Let m (i, j) be a QoS metric for link (i, j). For a path P=(s, i, j,…..l,t), metric m is concave if m(P) = min{m(s,i), m (i,j),.,m(l,t)}. Metric m is additive if m (P) = m(s, i) + m (i, j) +…+ m (l, t).

Based on the above definition, the bandwidth request is “concave” - the (available) bandwidth of a connection is the minimum of the (available) link bandwidth over the links along the path which is also called the bottleneck bandwidth of the path. Delay and jitter metrics are additive. The end-to-end delay or jitter is the accumulation of all delays or jitters of the links along the path The loss ratio constraint, however, is more complex: the loss ratio of the path (link_a, link_b, link_n) = 1- (1- loss ratio of link_a) x (1- loss ratio of link_b) x ...x (1-loss ratio of link_n).

The QoS condition of a network reflects the network’s ability to provide the specified service between communication pairs. Because of the rising popularity of multimedia applications and real-time services, which require strict bandwidth/delay constraints together with the potential commercial usage of Ad-Hoc networks, QoS support in the MANET has become a topic of interest in the wireless area.

2.3 QoS approaches in Ad-hoc networks

In this Section, we review existing approaches in the provision of QoS in ad-hoc networks.

2.3.1 MAC QoS

The MAC approach provides QoS support at the media access control (MAC) layer. Radio channels are shared media, and can be shared differently to provide service differentiation for instance by assigning larger slots for higher priority packets. The 802.11 MAC protocol parameters, such as the Interframe spacing (IFS), Contention Window (CW), and Backoff Integer (BI) have been suggested for QoS support.

Best-effort distributed MAC controllers are widely used in wireless ad-hoc networks. The IEEE 802.11 Distributed Coordination Function (DCF) is a good example of a best-effort distributed MAC. The Enhanced Distributed Coordination Function (EDCF) is a growing IEEE 802.11 alternative that facilitates prioritized packet transmission [32]. Recently, there have been a number of proposals to support service differentiation at the MAC layer using distributed control schemes like [2] .
In our work we focus on the evaluation of differentiation services at this layer. Based on theses evaluation we propose a QoS flow reservation strategy see chapter 5.

2.3.2 QoS-aware routing

QoS-aware routing considers the QoS dimension when performing route selection and packet scheduling. Embedding QoS in routing mechanisms can solve many of the problems faced during the QoS implementation on fixed wired networks running classical routing algorithms such as OSPF (Open Shortest Path First) [26]

The QoS-aware routing approach is still in early research phase in the ad-hoc networks, and limited numbers of proposals have evolved so far. For example, the Ad-hoc On-demand Distance Vector (AODV) protocol proposed in [25] [31], the Dynamic Source Routing (DSR) protocol proposed in [24], and the Optimized Link State Routing (OLSR) protocol proposed in [3]. QoS routing is valuable in finding optimal QoS routes, complementary to other approaches, but incomprehensive since it cannot perform service recovery, route maintenance, or process QoS reports. CEDAR [33] proposes a core extraction distributed routing algorithm that maintains a self organizing routing infrastructure, called the “core”. The core nodes establish a route that satisfies the QoS constraints on behalf of other nodes. None of these approaches significantly diverge from QoS approaches for wired networks, and they do not significantly address the differences between wired and wireless networks. In our work we are utilizing Hello messages from AODV. When AODV is used as routing protocol it periodically broadcasts a HELLO message to all neighbours. When a node receives a HELLO message it knows that the sending is a neighbor and will update the routing table. By extending the HELLO messages, we can include bandwidth information from the neighbors hence help in making accurate admission control and reservations.

2.3.3 Inter-layer QoS model Solutions

The inter-layer QoS model operates over different routing mechanisms and various media access layer. The inter-layer QoS model approach, in a sense, follows the flavor of QoS solutions for fixed topology networks namely by viewing routing mechanisms as one distinct component that can interact with the QoS model. This approach has started by importing solutions from fixed wired topology networks as in Flexible QoS Model for mobile ad-hoc networks (FQMM) [38].FQMM combines a reservation mechanism for high-priority traffic (IntServ) and a service differentiation (DiffServ) for low-priority data. Other approaches have realized the unique characteristics of ad-hoc networks as in in-band Signaling (INSIGNIA) [23] and Stateless Wireless Ad-hoc networks (SWAN) [4]. INSIGNIA uses an in-band signaling protocol for distribution of QoS information. The information is included in the IP headers of the data packets, and the available resources are calculated at each station the packet traverses so that a QoS decision can be made. SWAN [4] improves INSIGNIA by introducing an Additive Increase Multiplicative Decrease (AIMD)-based rate control algorithm. Specifically, Explicit Congestion Notification (ECN) is used to dynamically regulate admitted real-time sessions

The inter-layer QoS approaches provide comprehensive solutions but are less efficient since they cannot perform optimization at both MAC and routing layers. Note that FQMM propose little more than a mere extension to the wire-line QoS models. Recently, researchers started to realize the peculiar nature of the ad-hoc networks hence started to approach the issue of QoS from a cross layer design perspective.

2.3.4 QoS-aware application

QoS-aware applications form a set of applications that can adapt to limited variations in the service provided by the network and hide such variations from the application user. For example, [13] provides a through analysis of QoS-aware applications, and tries to enhance application adaptability to variable levels of services. QoS-aware significantly evolved over the last decade or so. Used techniques vary between compression algorithms, layered encoding, rate shaping, and adaptive error control. It is conceivable that some modifications and improvements are required for ad-hoc environments. QoS-aware applications cannot solve all MANETs QoS challenges like fading of wireless channels that can be solved by rerouting. QoS-aware applications can help providing the user with seemingly reasonable network performance.

2.4 Types of QoS Applications

QoS applications can be divided into different classes using different approaches. Applications may be classified into *Real-time* (RT) and *Elastic* applications. RT-applications need packets to arrive within certain time limits, and will disregard packets arriving past that time. Elastic applications can tolerate delays of arrival, and can afford to wait for packets.

2.4.1 Real-Time Application

One important class of RT-application is the class of playback applications where a source host issues a stream of packets and the packets travel over the network. The network introduces some delay variations to the packets. The destinations receive the packets and try faithfully to regenerate the original stream. In order for the destination to maintain a stable rate for the reproduced stream signal, it introduces a fixed delay. This delay allows the destination to buffer received data, and hides the delay variations from the application and user.

The performance of playback applications is measured by latency and reliability. Some playback applications that require duplex communication such as digital telephony (VOIP) require as sufficient level of interaction between both ends, and hence are more sensitive to latency. Others like streaming of a movie or lecture are not sensitive to latency. Similarly, it is possible to classify playback application as tolerant or intolerant to loss of fidelity. Intolerant applications need to obtain from the network information about a guaranteed upper bound on the maximum delay of each packet.

Predictive services on the other hand are proposed for tolerant applications since they can cope with some delays. The delay bound is not computed based on maximum delay; instead, it is computed based on conservative predictions about the behaviour of the flow. The network may violate the delay bound, and the application performance will certainly be impacted, however, the application users may be willing to accept the statistical possibility of lower application performance in return for lower cost. The deterministic guarantee bound delay and the statistical guarantee bound delay together help driving higher levels of network utilization.

2.4.2 Elastic Applications (BE-Service)

Elastic applications are able to wait for data to arrive. This does not mean elastic applications are insensitive to traffic delays. To the contrary, significant delays to packets will often harm application performance. However, this category of applications does not buffer incoming traffic, instead, it used the data immediately. Therefore elastic applications do not need a priori characterization of data, and the performance of the application depends more on the average packet delay. Examples of elastic applications are: interactive burst (Telnet, X, NFS), interactive bulk transfer (FTP), asynchronous bulk transfer (e-mail) and Hyper-Text Transfer Protocol (HTTP). The delay requirements for these elastic applications vary from rather demanding, to rather tolerant with interactive bulk transfer being somewhere in the middle [5].

2.5 QoS Challenges in MANETs

The dynamics of ad-hoc networks in terms of node mobility, limited battery power, and variable radio quality, make it difficult for real-time applications with appropriate QoS. The network dynamics also make it difficult to assign a central controller to maintain connection state and reservations. Major QoS challenges facing ad-hoc networks can be summarized as follows:

1. QoS challenges due to mobility of nodes. These challenges make it difficult to maintain resources on specific routes. The network dynamics impose inherent limitations to QoS promises in terms of connectivity, and robustness.
2. QoS challenges due to unpredictable link properties such as interference with other wireless devices, signal fading, or hidden node issues. This problem results in variant resources even on a fixed route and even assuming no mobility, for instance, due to interference with, potentially, wireless devices outside the ad-hoc network. The unpredictability of a wireless link causes potential variations in the link capacity, and therefore, inherent limitations on the expected QoS guaranties. This challenge makes flow reservation difficult to attain in ad-hoc networks.
3. QoS challenges due to limited capabilities of mobile nodes in terms of processing power, storage capacity, or energy. The limited capabilities challenge, influence, and shape the QoS design for instance by forcing a distributed approach, avoiding lookup tables, accommodating dormant devices, or adopting simpler lightweight algorithms.

4. QoS challenges due to the lack of central authority that can maintain central information on flows, routes, or connections. The challenge here is to design a decentralized QoS schemes.
5. QoS challenges due to Hidden and Exposed Terminal Problems: In a MAC layer with the traditional carrier sense multiple access (CSMA) protocol, multihop packet relaying introduces the "hidden terminal" and "exposed terminal" problems. The hidden terminal problem happens when signals of two nodes, say A and C, that are out of each other's transmission ranges collide at a common receiver, say node B (see Figure 2). An exposed terminal problem will result from a scenario where node B attempts to transmit data A while node C is transmitting to node D. In such a case, node B is exposed to the transmission range of node C and thus defers its transmission even though it would not interfere with the reception at node D (see Figure 2).

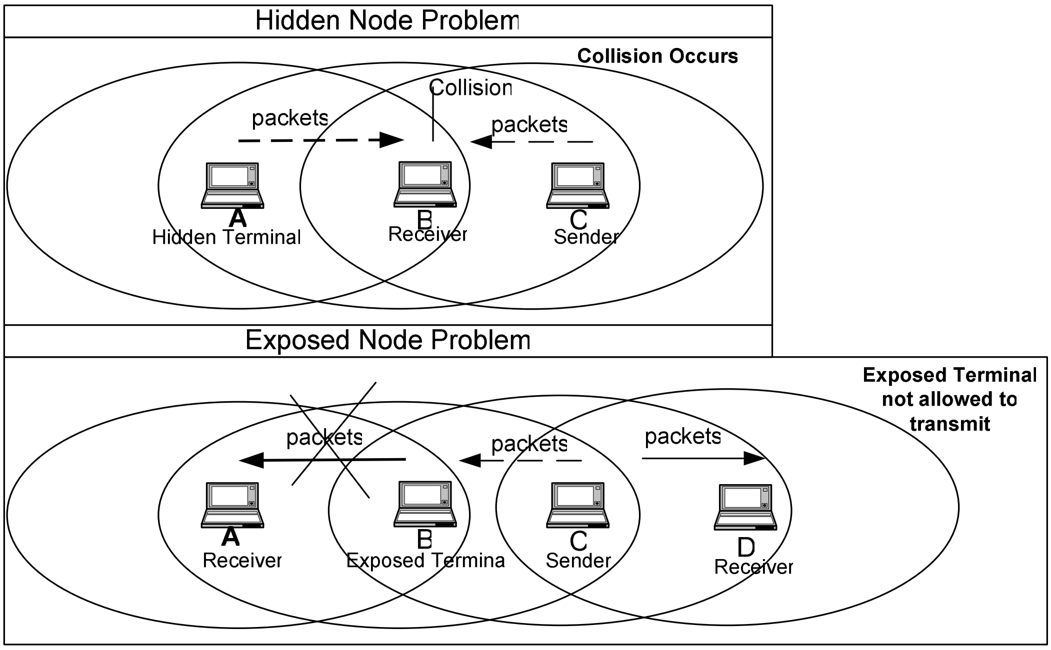

Figure 2 . Illustration of Hidden and Exposed Node Problems

All these challenges lead to serious concern in the provision of quality of service in ad-hoc networks. Some of these challenges influence greatly the issue of flow reservation in ad-hoc networks.

2.6 IEEE 802.11

In general, the IEEE 802.11 [34] standard covers the MAC sub-layer and the physical (PHY) layer of the OSI (Open System Interconnection) network reference model. Logical Link Control (LLC) sub-layer is specified in the IEEE 802.2 standard. This architecture provides a transparent interface to the higher layer users: stations may move, roam through an 802.11 wireless network and still appear as stationary to 802.2 LLC sub-layer and above. This allows existing network protocols (such as TCP/IP) to run over IEEE 802.11 wireless without any special considerations, just like if IEEE 802.3 wired Ethernet was deployed.

At PHY layer, first the IEEE provides three kinds of options in the 2.4 GHz band. The three PHY layers are an Infrared (IR) baseband PHY, a Frequency Hopping Spread Spectrum (FHSS) radio and a Direct Sequence Spread Spectrum (DSSS) radio. All three PHY layers support both 1 and 2Mbps operation. In 1999, the IEEE defined up to 11Mbps 802.11b in the 2.4 GHz free ISM (Industrial, Science, and Medical) band and up to 54Mbps 802.11a OFDM in 5GHz frequency. Ongoing 802.11g will extend 2.4GHz 802.11b PHY layer to support at least 20Mbps rate. Moreover, 802.11h will enhance 802.11a in the 5GHz band, adding indoor and outdoor channel selection for 5GHz license exempt bands in Europe. At MAC layer, ongoing 802.11e covers QoS support to the 802.11 wireless networks. 802.11i will enhance security and authentication mechanisms for 802.11 MAC.

The IEEE 802.11 MAC sub-layer defines two relative medium access coordination functions, the Distributed Coordination Function (DCF) and the optional Point Coordination Function (PCF).The transmission medium can operate both in contention mode (DCF) and contention-free mode (PCF). The IEEE 802.11 MAC protocol provides two types of transmission: asynchronous and synchronous.

The asynchronous type of transmission is provided by DCF which implements the basic access method of the 802.11 MAC protocol. DCF is based on the Carrier Sense Multiple Access with Collision Avoidance (CSMA/CA) protocol, and should be implemented in all the stations. The synchronous service (also called contention free service) is provided by PCF which basically implements a polling-based access method. In this thesis will concentrate on DCF since it’s the one which is used in ad-hoc networks.

2.6.1 Distributed Coordination Function (DCF)

The basic scheme for DCF is *Carrier Sense Multiple Access* (CSMA). This protocol has two variants: Collision Detection (CSMA/CD) and Collision Avoidance (CSMA/CA).

A collision can be caused by two or more stations using the same channel at the same time after waiting a channel idle period, or (in wireless networks) by two or more hidden terminals emitting at the same time.

CSMA/CD is used in Ethernet (IEEE 802.3) wired networks. Whenever a node detects that the transmitted signal is different from the one on the channel, it aborts transmission, saving useless collision time. This mechanism is not possible in wireless communications, as nodes cannot listen to the channel while transmitting, due to the big difference between transmitted and received power levels. In this case, after each frame transmission the sender waits for an acknowledgment (ACK) from the receiver, as shown in Figure 3

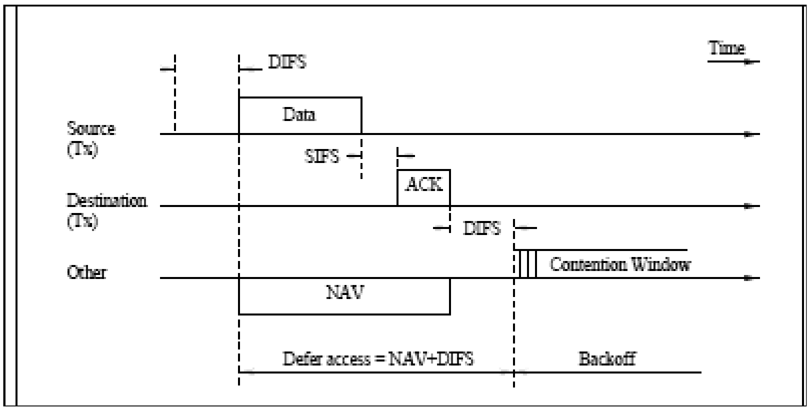

Figure 3. Basic Access Scheme

Source axis shows data transmitted by the source. The destination responds by an ACK, represented on the *Destination* axis. The third axis represents the network state, as seen by *other* nodes. Note that transmission delays are not shown. The Interframe Spacings DIFS and SIFS will be explained later in this Section.

If no ACK was returned, a collision must have occurred and the frame is retransmitted. But this technique may waste a lot of time in case of long frames, keeping transmission going on while congestion is taking place (caused by a hidden terminal for example). This can be solved by introducing an optional RTS/CTS scheme (Request To Send and Clear To Send respectively), in addition to the previous basic scheme.

In the *optional RTS/CTS scheme*, a station sends an RTS before each frame transmission for channel reservation. The destination responds with a CTS if it is ready to receive and the channel is idle for the packet duration. When the source receives the CTS, it starts transmitting its frame, being sure that the channel is "reserved" for the frame duration. All other nodes update their *Network Allocation Vector* (NAV) at each hearing of RTS, CTS and the data frames. NAV is used for *virtual carrier sensing*, detailed in the next paragraph.

This scheme is shown in Figure 4. The overhead caused by the transmission of RTS/CTS frames becomes considerable when data frames sizes are small and sub-optimal channel usage takes place. Reference [10] discuss optimal data frame sizes (*RTS Threshold*) above which it is recommended to use the RTS/CTS scheme.

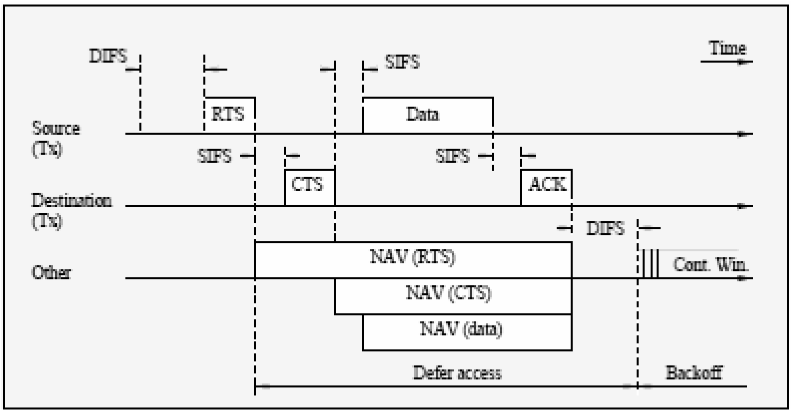

Figure 4 RTS/CTS Access Scheme

Not all packet types have the same priority. For example, ACK packets should have priority over RTS or data ones. This is done by affecting to each packet type a certain *Interframe Spacing* (IFS) before which a packet cannot be transmitted, once the channel becomes idle. In DCF two IFSs are used: Short IFS (SIFS) and DCF IFS (DIFS), where SIFS is shorter than DIFS (See Figure 3 and Figure 4). As a result, if an ACK (affected with SIFS) and a new data packet (affected with DIFS) are waiting simultaneously for the channel to become idle, the ACK will be transmitted before the new data packet (the first has to wait SIFS whereas the data has to wait DIFS.)

Carrier sensing can be performed on both layers. On the physical layer *physical carrier sensing* is done by detecting any channel activity caused by other sources. On the MAC sub-layer, *virtual carrier sensing* can be done by updating a local NAV with the value of other terminal’s transmission duration. This duration is declared in data frames, RTS and CTS frames. Using the NAV, a node MAC knows when the current transmission will end. NAV is updated upon hearing an RTS from the sender and/or a CTS from the receiver, so the hidden node problem is avoided. In our work will use this mechanism to estimate the available bandwidth to be reserved.

The collision avoidance part of CSMA/CA consists of avoiding packet transmission right after the channel is sensed idle (+ DIFS time), so it won't collide with other "waiting" packets. Instead, a node with a packet ready to be transmitted waits a random time after the channel being idle for DIFS, backoff time, shown in Figure 3 and Figure 4. Backoff time of each node is decreased as long as the channel is sensed idle (during the called *contention window*). When the channel is busy, backoff time is freezed. When backoff time reaches zero, the node transmits its frame, but if the channel is sensed busy because of another "waiting" frame, the node computes a new random backoff time, with a new range. This range increases exponentially as 2^{2+i} where i (initially equal to 1) is the transmission attempt number. Therefore, the backoff time equation is:

$$\textit{Backoff time} = [\, 2^{2+i} * \mathrm{rand}\,()\,] * \textit{Slot\_Time} \ldots \quad \textbf{[2.1]}$$

Where Slot_time is function of some physical layer parameters, and rand () is a random function with a uniform distribution in [0, CW]. There is a higher limit for retransmission attempts i, above which the frame will be dropped. Collision avoidance is applied on data packets in the basic scheme, and on RTS packets in the RTS/CTS scheme.

All nodes have equal probability to access the channel, thus share it equally. But this method has no guarantees for queuing delays and has no service differentiation see Section 2.7, so it is not optimal for time-bounded applications.

2.6.2 QoS Issues in DCF

DCF can only support best-effort services, not any QoS guarantees. Typically, time-bounded services such as Voice IP, audio and video conference require specified bandwidth, delay and jitter, but can tolerate some losses. However, in DCF mode, all the stations in the network or all the flows in one station compete for the resources and channel with the same priorities. There is no differentiation mechanism to guarantee bandwidth, packet delay and jitter for high-priority stations or multimedia flows. Throughput degradation and high delay are caused by the increasing time used for channel access contention. See chapter 4 for analysis of DCF differentiation mechanisms.

2.6.3 IEEE802.11e (EDCF)

EDCF [32] is a main part of the upcoming 802.11e [14] standard for service differentiation. It prioritizes traffic categories by different contention parameters, including arbitrary Interframe space (AIFS), maximum and minimum backoff window size (CWmax/min), and a multiplication factor for expanding the backoff window. Although all traffic categories keep using the same DCF access method, they have different probabilities of winning the channel contention by differentiating contention parameters.

EDCF makes two improvements for providing differentiation. First, it includes a QoS parameter set element which sets the contention window values and AIFS (Arbitration Interframe Space) values for prioritized EDCF channel access during the contention period. Classes with smaller AIFS have higher priority. Second, to achieve better medium utilization, packet bursting is used, i.e., when a station has gained access to the medium, it can be allowed to send more than one frame without contending for the medium again. EDCF provides good traffic differentiation, but it causes starvation of low priority flows under high traffic load.

2.7 Service Differentiation

Service differentiation is an important aspect of providing QoS in wireless networks. In this Section we look at service differentiation mechanisms and how they provide QoS in wireless ad-hoc networks. We then highlight the challenges this aspect faces in regard to flow reservation and admission control.

In many ad-hoc network applications, such as disaster rescue, communication terminals may have different priority ranks. Many applications that are deployable in ad hoc networks, such as multimedia applications, may have different delivery requirements, i.e., low delay and jitter, and high throughput. For instance, a typical Voice over IP (VoIP) traffic session has the requirement of very low transmission delay. While multimedia streaming traffic is more tolerant to latency than VoIP traffic, it requires more bandwidth. We can therefore label different traffic classes with different priority levels and provide service differentiation among traffic flows.

The essential problem of providing QoS in multi-hop ad-hoc networks is trying to admit as many traffic flows as possible in order to achieve high efficiency of the channel usage, while at the same time providing service quality guarantees according to traffic priority.

A number of recent proposals allow service differentiation among stations or even among traffic classes, in the 802.11 standard. This differentiation is archived by assigning different priorities in the wireless medium access to stations that contend for it. These proposals suggest modifications to the DCF mode.

These techniques can be classified according to the parameter used to archive differentiation: *DIFS*, *backoff*, *frame size*, and *RTS/CTS threshold*.
The *DIFS-based scheme* consists of configuring wireless stations with different values for this parameter according to the priority that one wishes to assign to each station. The larger the DIFS in the number of slots, the smaller the station priority. To avoid contention among stations with different priorities, the maximum contention window of a station with priority j added to $DIFS_j$ is chosen in such a way that it is never larger than $DIFS_{j+1}$ (lower priority). This guarantees that a higher priority station has no frames to send when a lower priority station starts transmitting.

The *backoff-based scheme* consists of assigning different intervals (min and max) for the contention window of each station or determining how the contention window evolves along with station/flow priority, number of retransmission retrials, and other factors. In [2], the contention window intervals are calculated according to the priority established for each station. Aad et al [1] also present a mechanism that assigns different priorities for different destinations, i.e., per-flow differentiation. In [18][19], the authors propose a scheme where the priority of the next frame to be sent is included in RTS and CTS control frames, data frame, and the corresponding ACK. Since all stations in the same coverage area hear this information, they can maintain a table with the current head-of-line frames of all stations that contend for the medium. The contention window interval is then calculated by each station according to the position (rank), in terms of priority, of its frame in that table. This scheme does not provide an admission control mechanism, resulting in performance degradation as the traffic load increases.

Bensaou et al [36] propose a scheme of differentiated backoff according to the estimate of its bandwidth share and the share obtained by the other stations. The main idea is to allow all stations to transmit using the default configuration if the total load is smaller than the link capacity. In case of exceeding the link capacity, each station should obtain an access proportional to sharing index previously established in the admission control.

The two schemes described below establish a coarser differentiation. In the technique based on the frame size, stations with higher priority use larger frame sizes in their transmissions. This scheme controls the time a station retains the medium after winning a contention for it.

The technique based on the *RTS/CTS threshold* consists of the use of medium reservation through the RTS/CTS handshake. Stations with threshold values larger than frame sizes of a certain flow will not use RTS/CTS. These frames will have higher collision probability and consequently a lower priority.

In our work we will mainly concentrate and evaluate DIFS-*based and backoff-based schemes* because they are schemes where the currently effort to provide QoS in 802.11e is based.

2.8 Admission Control

Admission control aims to provide a path, from source to destination, containing enough free resources to carry a flow, without interfering with nearby ongoing traffic. Since we are assuming a shared medium, the routing protocol (AODV) must be able to access bandwidth related information of every node on the path, as well as their first hop neighbours.

Basically, admission control schemes can be broadly classified into measurement-based and calculation-based methods. In measurement-based schemes, admission control decisions are made based on the measurements of existing network status, such as throughput and delay. On the other hand, calculation-based schemes construct certain performance metrics or criteria for evaluating the status of the network. In our approach the admission is performed at the network layer of the OSI and is based on calculation-based scheme.

Wireless networks generally have limited resources in terms of both device capabilities and available network bandwidth. Consequently, it is beneficial to have call admission to prevent unprovisioned traffic from being injected into the network beyond the saturation point. If a flow has rigid QoS requirements, an admission mechanism will prevent the waste of resources of both the source node itself and the whole network, if the network cannot support the flow.

Wireless communication channels are shared by all nodes within transmission range; consequently, all nodes within a transmission area contend for the limited channel bandwidth. In a multi-hop scenario, an admitted flow at a source node does not only consume the source's bandwidth, but the bandwidth of all the neighboring nodes along the data propagation path, thereby affecting ongoing flows of other nodes. Hence, it is essential to perform admission control along the entire path.

Efficient Connection Admission Control and reservation are very essential in providing QoS. Papers like [35] do address the Admission Control, but a simple and efficient in-built Admission Control and reservation mechanism is not provided for ad-hoc networks so far. Performing Admission Control and flow reservation in a distributed manner with no single node having to burden the task is the real challenge in ad-hoc networks.

2.9 Flow Reservation

The resource reservation arranges for the allocation of suitable end-system and network resources to satisfy the user QoS specification. In so doing, the resource reservation interacts with the QoS routing protocol to establish a path through the network in the first instance, then, based on admission control at each node, end-to-end resources are allocated.

RSVP (Resource Reservation Setup Protocol) [6]) is a signaling mechanism to carry the QoS parameters from the sender to the receiver to make resource reservations along the path. The mechanism works as follows:

(i) The sender of an application sends PATH messages containing the traffic specifications to the receiver(s) of the application that will use this reservation.

(ii) The receiver receives this PATH message and sends RESV message to the sender specifying the flow it wants to receive.

(iii) As the RESV message flows back to the sender, reservations are made at every node along the way. If at any point along the path the request cannot be supported, that request is blocked.

(iv) At every router/host along the way, path and reservation states are maintained for every application session. Periodically sent PATH and RESV messages refresh the path and reservation states.

RSVP is designed to provide integrated service for packet-switched network such as IEEE802.3. However, because of the scarcity of bandwidth and high link error in wireless network, directly applying RSVP may lead to high overhead and instable performance hence not suitable for our situation. The our reservation procedure is described in Section 3.4

2.10 Description of AODV

In this Section we give a brief description of the routing protocol on which are our work will partially depend. Appendix C gives a detailed account of how the protocol operates.

The Ad Hoc On-Demand Distance Vector (AODV) routing protocol [30] enables multi-hop routing between participating mobile nodes wishing to establish an ad-hoc network. It's basically a combination of DSDV and DSR. It borrows the basic on-demand mechanism of Route Discovery and Route Maintenance from DSR, plus the use of hop-by-hop routing, sequence numbers, and periodic beacons from DSDV. AODV minimizes the number of required broadcasts by creating routes on an on-demand basis, as opposed to maintaining a complete list of routes as in the DSDV algorithm. Authors of AODV classify it as a pure on demand route acquisition system since nodes that are not on a selected path, do not maintain routing information or participate in routing table exchanges.

Features of this protocol include loop freedom and that link breakage cause immediate notifications to be sent to the affected set of nodes, but only that set. It uses destination sequence numbers to guarantee freshness of a route.

The algorithm uses different messages to discover and maintain links. Whenever a node wants to try and find a route to another node, it broadcast a Route Request (RREQ) to all its neighbours. The RREQ propagates through the network until it reaches the destination or a node with a fresh enough route to the destination. Then the route is made available by unicasting a Route Reply (RREP) back to the source.

The algorithm uses HELLO messages (a special RREP) that are broadcasted periodically to the immediate neighbors. These HELLO messages are local advertisement for continued presence of the node and neighbor using routes through the broadcasting node will continue to mark the routes as valid. If hello messages stop coming from a particular node, the neighbor can assume that the node has moved away and mark that link to the node as broken and notify the affected set of nodes by sending a link failure notification (a special RREP) to that set of nodes.

2.10.1 Route discovery

A node broadcasts a RREQ when it needs a route to a destination and does not have one available. This can happen if the route to the destination is unknown, or if a previously valid route expires. After broadcasting a RREQ, the node waits for a RREP. If the reply is not received within a certain time, the node may rebroadcast the RREQ or assume that there is no route to the destination.

Forwarding of RREQs is done when the node receiving a RREQ does not have a route to the destination. It then broadcast the RREQ. The node also creates a temporary reverse route to the source IP Address in its routing table with next hop equal to the IP address field of the neighboring node that sent the broadcast RREQ. This is done to keep track of a route back to the original node making the request and might be used for an eventual RREP to find its way back to the requesting node. The route is temporary in the sense that it is valid for a much shorter time than an actual route entry.

When the RREQ reaches a node that either is the destination node or a node with a valid route to the destination, a RREP is generated and unicasted back to the requesting node. While this RREP is forwarded, a route is created to the destination and when RREP reaches the source node, there exists a route from the source to the destination.

2.11 Network Simulator (NS-2)

Network Simulator 2 (NS-2) [28] is a simulation tool that originated from Lawrence Berkeley National Laboratory. It is targeted at networking research and based on discrete events simulations.

The simulator is written in C++ and it uses OTcl as a command and configuration interface. This means that OTcl scripts are used to set up simulation scenarios in the simulator. One great benefit of this is that there is no need to recompile the simulator between different simulations since you are able to set up topology, link bandwidth, traffic sources etc, from the OTcl scripts. So, once you have implemented the basic functionality within the simulator (C++ code) you only have to change the OTcl scripts to run various simulations.

NS-2 provides substantial support for simulation of routing and multicast protocols over wired and wireless networks. NS-2 has an advanced 802.11 module, which is applied and verified extensively in the network community. Because simulation with 802.11 is essential in our research, NS-2 is an excellent simulation tool within this scope.

NS-2 is a popular tool among the researchers in both the wired and wireless world. It has been used to obtain vast amount of simulation results used in various papers.

The idea of a discrete event scheduler is that actions may only be started as a result of an event. In NS-2 this is taken care of by a scheduler and a scheduling list. Events are inserted into scheduling list upon request, together with their expiration time. The scheduler is responsible to go through the list and perform the necessary actions.

Simulations in NS-2 can be logged to trace files, which include detailed information about received and transmitted packets and allow for post-run processing with some analysis tools. Figure shows a simplified view of NS-2

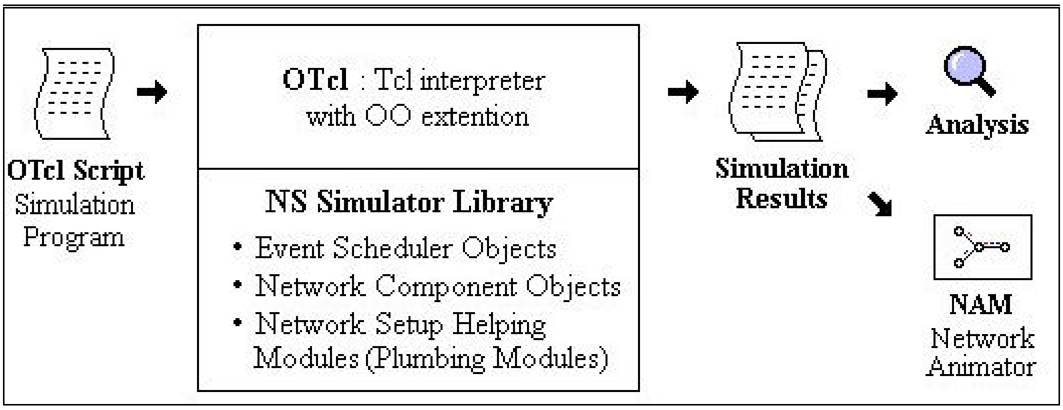

Figure 5. Simplified User's View of NS-2

2.11.1 IEEE 802.11 in NS-2

Within the DCF implementation, a packet is handed by the LLC through an advanced drop-tail interface queue to its MAC. Beacons are not really included but routing update messages are transmitted in each interval of several seconds.

The DCF MAC protocol can handle DATA/ACK/RTS/CTS, as well as the broadcasting type of packets. Both physical and virtual carrier sense are supported. The Interframe space intervals SIFS, PIFS, DIFS are implemented accordingly. EIFS is also implemented and applied after each unsuccessful transmission attempt.

Within each station only one queue is present for all the awaiting packets. This queue is controlled by several timers defined in the NS-2 MAC: defer time, backoff timer, interface timer, send timer and NAV timer. These timers start upon certain events and are responsible to insertion of new events into the scheduling list. There is also a procedure present to cancel/pause these timers. After a timer expires, a handling procedure is called to execute the required follow–up actions.

NS-2 includes all three PHY layer specifications: Frequency Hopping Spread Spectrum (FHSS), Direct Sequence Spreading Spectrum (DSSS) and Infra-red (IR).

Within NS-2 a capture threshold is also implemented. It relies on the received power strength and may retrieve one packet correctly even if it collides with other packets. However, this effect can be excluded by applying an extremely high capture threshold.

2.12 Related Work

The QoS issues in ad hoc networks are challenging tasks due to the dynamic aspects of these networks and their bandwidth constraints. Existing work on QoS in ad-hoc networks is categorized in Section 2.3. Most QoS approaches borrow ideals from wired networks i.e. DiffServ [12] and IntServ [15]. Due to the impossibility of using these approaches, alternative solutions have been proposed for the problem. Some of them (like the SWAN project [4]) are based on DiffServ idea, i.e., on the classification of traffic into classes that are served with different priorities by the network. Others like the Flexible Quality of Service Model (FQMM) [38] combine a reservation mechanism for high-priority traffic and a service differentiation for low-priority data. Many other proposals may be found in the literature and each of them faces the problem in a different way. Examples of them are INSIGNIA [23] (which uses in-band signaling), CEDAR [33] (which defines a “backbone” in order to reduce signaling overhead). Other Reservation schemes can be found in [39] [7] [8].

Most of these approaches significantly diverge from QoS approaches for wired networks, but they do not completely address the differences between wired and wireless networks. Specifically, they often do not consider the contentious nature of the MAC layer, nor the neighbor interference on multihop paths. This leads to inaccurate path quality prediction for real-time flows. Additionally, most of the work does not consider the fact that a newly admitted flow may disrupt the quality of service received by ongoing real-time traffic flows.

Furthermore, service differentiation is often desired in ad hoc networks. Most of the solutions do not provide accurate quality estimation when flows of multiple priorities exist. Recently, other works have proposed the performance improvement of MAC protocols and the support of service differentiation. Many of these approaches specifically target IEEE 802.11. For example, studies in [2] propose to tune the contention windows sizes or the inter-frame spacing values to improve network throughput, while studies in [2] [18] propose priority-based scheduling to provide service differentiation. Most of this work utilizes different backoff mechanisms, different DIFS lengths, or different maximum frame lengths, based on the priority of the traffic.

Based on the previous work especially on the problems inherent in service differentiation, we propose a flow reservation strategy through bandwidth reservation along the path that connects two mobile nodes. Our strategy tries to solve the problem of determining interference caused by transmission between two nodes in an IEEE 802.11 ad-hoc network in other nodes that are in their coverage area.

2.13 Summary and thesis approach

In this chapter we have looked at QoS approaches, type of QoS application, and service differentiation at the MAC layer and then provided necessary information regarding admission control and flow reservation.

Most of these service differentiation mechanisms describe in Section 2.7 above lack admission control mechanism and flow reservation hence as traffic load increases, performance degrades drastically. DCF suffers seriously from collisions under high loads, and it does not provide any traffic differentiation. Finally, the proposed mechanisms provide QoS differentiation, but no guarantees of QoS levels can be made without admission control and resource allocation. We are approaching these issues by first conducting an evaluation of service differentiation mechanisms in order to characterize the shortcomings of these systems. And then provide a theoretical proposal to help counteract these shortcomings by the way of QoS flow reservation.

CHAPTER 3. METHODOLOGY

In this chapter, we are discussing our approach to try to address the problems described in the problem statement. In Section 3.1 we present the introduction. Section 3.2 describes how to estimate the available bandwidth needed to be used by a node.

3.1 Introduction

There are many solutions cited in literature dealing with resource reservation and admission control. This research focus on the provision of QoS guarantees on top differentiation mechanisms stated in Section 2.7, through reservation and admission control. Our approach takes into account the issues of channel interference when estimating available bandwidth before admission control can be done. In our approach we are utilizing HELLO messages from AODV routing protocol to send bandwidth information to neighbours, so that they can make necessary reservations based on the available bandwidth. Our approach tries to solve the problem of determining interference caused by transmission between two nodes in an 802.11 ad-hoc network in other nodes that are in their coverage area.

In this thesis we are also highlighting the problems of differentiation mechanisms.
In order to solve these issues we first carry out an evaluation of service differentiation mechanisms by way of simulations. On the issue of tackling the problem described in the problem statement there is a need for nodes [1](stations) to be equipped with the following:

1. Resource estimation (estimating available bandwidth).
2. Admission control based on available bandwidth.
3. Flow reservation after the admission control.

These three factors are fundamental to greatly reduce the problems of traffic degradation as load increases in the network.

3.2 Resource Estimation

In a distributed ad hoc network, a host’s available bandwidth is not only decided by the raw channel bandwidth, but also by its neighbor’s bandwidth usage and interference caused by other sources, each of which reduces a host’s available bandwidth for transmitting data. Therefore, applications cannot properly optimize their coding rate

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[1] Note that we use node and station interchangeably in this thesis.

without knowledge of the status of the entire network. Bandwidth is a fundamental resource. When flows are routed through the network, estimating the remaining bandwidth is often required before performing admission control, flow management, congestion control or routing based on bandwidth constraints.

However, bandwidth estimation is extremely difficult, because each host has imprecise knowledge of the network status and links change dynamically. Therefore, an effective bandwidth estimation scheme is highly desirable. Bandwidth estimation can be done using various methods; for example, in [39] bandwidth estimation is a cross-layer design of the routing and MAC layers, and in [22], the available bandwidth is estimated in the MAC layer and is sent to the routing layer for admission control. Therefore, bandwidth estimation can be performed in several different network layers. We are using a similar approach described in [39].

To determine whether there is enough bandwidth available for a new flow, all we need to know is the available link capacity and the bandwidth to be consumed by the requesting flow. In wired networks this is a trivial task since the underlying medium is a dedicated point-to-point link with fixed capability.

However, in wireless networks the radio channel of each node is shared with all its neighbours. Because of the shared medium, a node can successfully use the channel only when all its neighbours do not transmit and receive packets at the same time. We call this the aggregation effect.

In [7] the authors derive formulae to estimate the available bandwidth in an ad-hoc network using shared links. To do so, each node may do the following calculation:

$$MUBi = Ci - \sum lij, \forall j \in Neighbourhood\ \ of\ \ i \qquad \textbf{[3.1]}$$

$MUBi$ is the maximum unused bandwidth, Ci is the capacity of the node and lij is the total traffic between nodes *i* and *j*.

But, since the traffic between neighbors of a node also interfere; these traffics must also be taken into consideration to calculate the maximum available bandwidth (*MABi*), what leads us to:

$$MABi = MUBi - \sum_{j} \sum_{k} ljk, \forall j \in Neighborhood - of - i, \forall k \in Neighborhood - of - j \quad \textbf{[3.2]}$$

Using Hello messages from AODV routing protocols, all nodes can broadcast their *MUB* and their local bandwidth requests. This makes sure that all nodes are aware of their neighbours' traffic demands. We have developed admission control algorithm to handle this situation (See chapter 5).

When using a reactive routing protocol, such as AODV, the *MAB* may be used to elect a path that fulfills the QoS needs of a flow. The Route Request (RREQ) messages checks the available bandwidth to be sure that the flow may pass through the node (if not, the RREQ is discarded). During the reverse path establishment (Route Reply), the resources may be then reserved.

The previous formulas, however, may not guarantee a correct calculation of the available bandwidth in the general case. Available bandwidth can be computed if the nodes know not only lij, but the $MABi$ computed by their neighbors. Then, the available bandwidth ABi to allocate new reservations at Node$_i$ is given by:

$$ABi = \min\{MABi, MABj\}, \forall j \in Neighborhood - of - i \quad \textbf{[3.3]}$$

3.3 Admission Control

Service differentiation is helpful in providing better QoS for multimedia data traffic under low to medium traffic load conditions. However, due to the inefficiency of IEEE 802.11 MAC, service differentiation does not perform well under high traffic load conditions as stated in the problem statement.

In service differentiation mechanisms, no assurance can be given to higher priority traffic in terms of throughput and delay performance. Admission control is an important tool to maintain QoS experienced by users. Our admission control algorithm takes into account the problem of determining interference caused by transmission between two nodes. By predicating the achievable throughput of data flows and avoiding channel overloading, the QoS of existing flows can be maintained. See chapter 5 for our proposed admission control. Admission control is based on local computation of the available bandwidth by each node of the network based on information that is sent by its neighbors through periodical HELLO messages.

3.4 Flow Reservation

The resource reservation arranges for the allocation of suitable end-system and network resources to satisfy the user QoS specification. In doing so, the resource reservation interacts with the QoS routing protocol to establish a path through the network in the first instance, then, based on admission control at each node, end-to-end resources are allocated.

For in-band signaling protocols for MANET such as INSIGNIA [23], the reservation control message is integrated together with the data packet. In our approach we are proposing using HELLO messages which are extended to include bandwidth field, which carries bandwidth information from neighbours. Reservation Request and Reply messages are integrated in AODV as described in [31]: the bandwidth reservation is included in a Route Request (RREQ) message as an extension object. The RREQ QoS extensions include a session-ID to identify the flows together with the Source and Destination addresses.

Upon receiving a RREQ, intermediate nodes apply the admission control algorithm. If the reservation is accepted, the RREQ is forwarded, and it is discarded otherwise. However, reservation is only done when the RREP is received (see Figure 6). Opposite to AODV, if an intermediate node has a route to a destination, this node should not answer with a route reply to the sender, since the intermediate node does not know whether further nodes can accomplish the bandwidth reservation. In order to avoid this situation the D flag of a RREQ is activated (see [29]) indicating that only the destination can send a RREP.

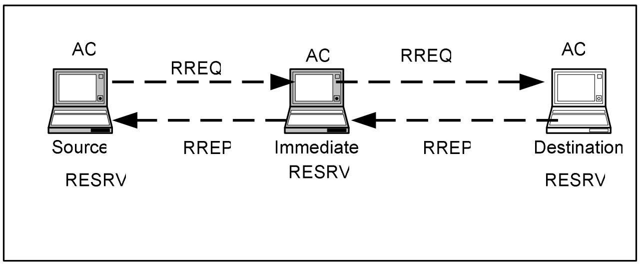

Figure 6. Reservation Procedure

In our reservation strategy we propose that a node only requires knowing the reservation and maximum available bandwidth of their neighbors. These quantities can be easily advertised by means of hello packets. See chapter 5 for details.

3.5 Tools Used

In this Section we describe some of the tools that are used to help us tackle the problem. In Section 3.5.1 we describe the NS-2 simulator, and then Section 3.5.2 we look at Xgraph and Gnuplot theses are used for plotting graphs and Section 3.5.3 we describe miscellaneous tools.

3.5.1 NS-2 Simulator

See Section 2.11 for the description of this simulation tool and Appendix A gives brief instructions on how to install NS-2 version 2.27 on Windows XP.

3.5.2 Xgraph and Gnuplot

Xgraph [37] and Gnuplot [20] are X-Window applications that include interactive plotting and graphing, and animation and derivatives. The programs are used to create graphic representations of simulation results. Output data from TCL scripts is used as data sets to Xgraph or Gnuplot. To use Xgraph in NS-2 the executable can be called within a TCL Script. This will then load a graph displaying the information visually displaying the information of the trace file produced from the simulation see Figure 7

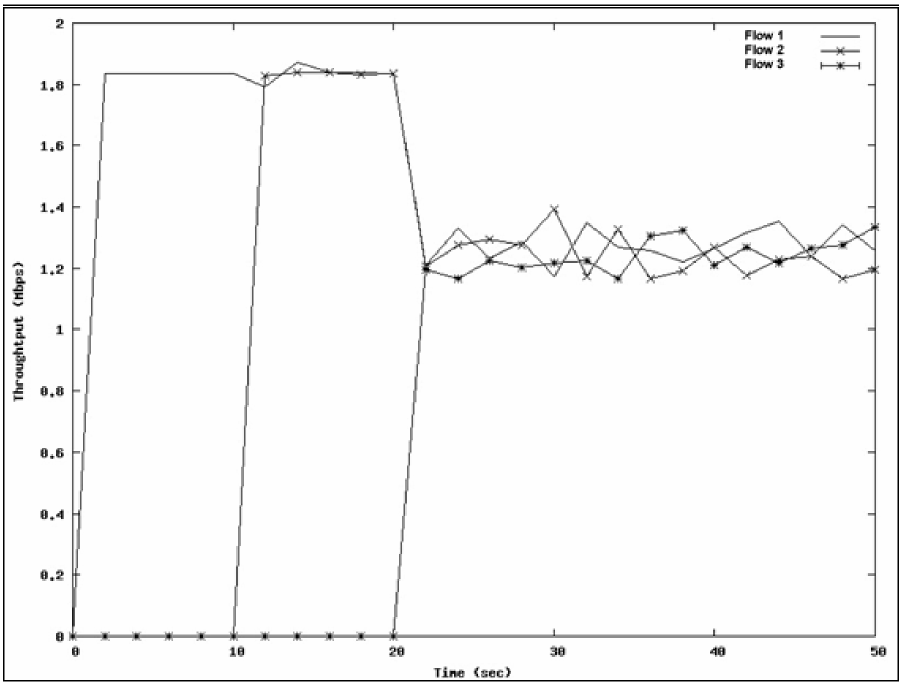

Figure 7. Gnuplot running comparing three trace files in a graph

3.5.3 Other tools

Other tools include AWK, *grep* and Perl scripts; these are mainly used to extract important statistics information from trace files. AWK utility allows us to do simple operations on data files such as averaging the values of a given column, summing or multiplying term by term between several columns. In our work we extensively used this utility to calculate and extract QoS metrics from trace files. The *grep* command in UNIX allows to "filter" a file. This is important because some generated trace files are enormous hence needs to be filtered. With *grep* we can create a new file which consists of only those lines from the original file that contain a given character sequence. For details type *man grep* on the UNIX command prompt.

CHAPTER 4. SIMULATION RESULTS

In this chapter, we aim at analysing the differentiation level offered by modifying MAC parameters, such as DIFS and contention window, in different scenarios and then expose shortcomings from theses mechanisms. We opted to use these parameters because they are very similar to 802.11e differentiation mechanism. The Network Simulator NS-2 [28] version 2.27 is used in the simulations studies. We have used the functionalities of 802.11 networks added with service differentiation, ad hoc routing (AODV) and Constant Bit Rate (CBR) traffic source.

In Section 4.1 we provide our simulation environment, Section 4.2 provide the results from our simulations and then in Section 4.3 we provide our observations and Analysis.

4.1 Simulation Environment

In this Section we describe the environment and the scenarios used in our simulations.

4.1.1 First Scenario

The topology used in the first experiment consists of three stations transmitting to a fourth station. All stations generate 1.8 Mbps CBR traffic with packet sizes of 1000 bytes. The distance between stations is 50 meters. The ad-hoc routing protocol is AODV and the channel capacity is 11Mbps. The maximum achievable throughput in this channel is largely dependent on the frame size used by the sources, the use of the RTS/CTS handshake, and the number of stations contending for the medium, and the differentiation parameters such as DIFS and the contention window. For example, when only one CBR source contends for the medium and uses packet of 1000 bytes, the maximum achievable throughput is about 3.6 Mbps. Stations 1,2 and 3 start their transmissions at 0s, 10s and 20s to station 0. The throughput obtained by each station at each 1 s interval is evaluated.

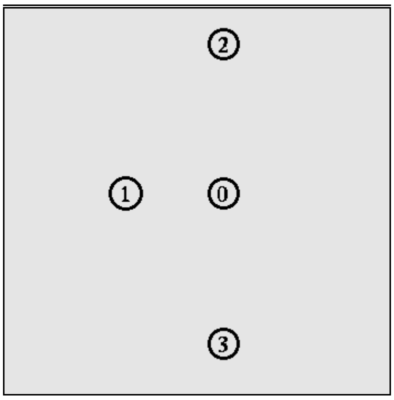

Figure 8. First Simulation Topology

4.1.1.1 First Simulation: No Differentiation

In the first simulation, no differentiation mechanism is used, i.e., all nodes have the default configuration for differentiation parameters, as show in the Table 1.

Table 1. Default Configuration Parameters for 802.11 DCF

Parameter	Value
DIFS	50us
CWmin	31
CWmax	1023

4.1.1.2 DIFS-based Scheme

The second simulation is that of DIFS-based scheme in which stations are given different DIFS parameters. Here we had to made changes to NS-2 to enable it expose the DIFS parameter so that each node uses its own value and then recompile it (See Appendix B). Parameters used are in Table 2.

Table 2. DIFS parameter for DIFS-based Scheme

Stations	DIFS	CWmin :CWmax
1	20us	31:1023
2	40us	31:1023
3	60us	31:1023

4.1.1.3 Backoff-based scheme

The third simulation is that of changing the contention window size and then study the behaviour of throughput. Each station is configured with a contention window interval [CWmin: CWmax] as show in Table 3. Stations with smaller intervals have higher priority of accessing the channel compared to stations with larger values. So we expect stations with smaller intervals values to have higher throughput compared to those with larger values.

Table 3. Contention Window Sizes

Station	CW (CWmin : CWmax)	DIFS
1	31 -1023	20us
2	63 -2047	20us
3	127- 4095	20us

4.1.2 Second Scenario: Increasing the number of stations

In this scenario we study the level of differentiation and how throughput behaves as the number of stations contending for the wireless channel increases. We are still using three types of priorities (classes) for both DIFS-based scheme and backoff-based scheme. All stations send traffic to one station and we maintain the same configuration parameters as stated in Section 4.1.1. The number of stations per priority class is increased from 3 to 10.

4.1.3 Third Scenario: Introducing Mobility

In third scenario we introduce some mobility so that we may understand the influence of mobility on differentiation and throughput. In this scenario, all stations follow a random generated movement pattern, called random-way point [21], in which transmitting stations always stay within the range of the receiving station. Average speed of each station is 10 m/s with movement pauses of 20 seconds in average. The number of stations is increased in each simulation run as described in Section 4.1.2. The movement pattern is generated by a utility found in NS-2 called *setdest.*

4.2 Results

In this Section we provide the results obtained from the different simulation scenarios described in Section 4.1. All graphs were obtained using Gnuplot and setting its terminal to jpeg.

4.2.1 No Differentiation (Pure DCF).

This first simulation shows the throughput of three CBR flows over DCF without any differentiation. This clearly shows how DCF is best-effort service in which each station is given equal bandwidth. Figure 9 shows the first station starts to transmit at 0 seconds and gets its required bandwidth (1.8Mbps), and then station 2 joins in after 10 seconds, it also gets its required bandwidth. But problems start after 20 seconds when station 3 transmits, the bandwidth reduces to about 1.2 Mbps for each station. The introduction of the third flow causes the total traffic to go up to 5.4Mbps (3 x 1.8 = 5.4Mbps), this is more than the maximum available bandwidth of about 3.6 Mbps (this is calculated according to the formula suggested in [16]).

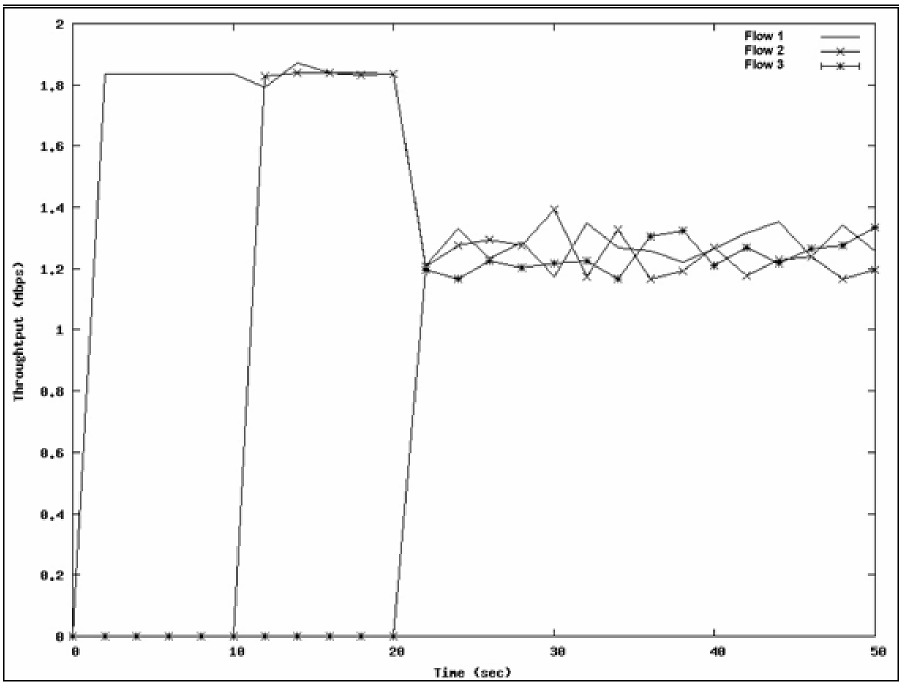

Figure 9. Throughput of 3 flows with No Differentiation

4.2.2 DIFS –based Differentiation

In this Section we provide results for DIFS-based differentiation.

4.2.2.1 First Scenario

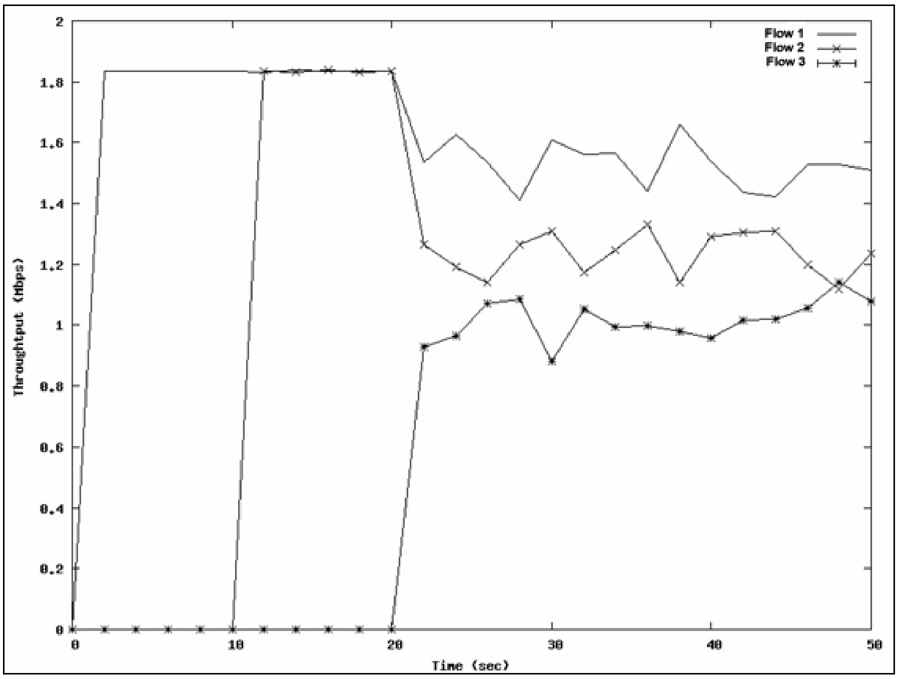

Figure 10. Throughput of 3 flows with DIFS-based Differentiation

Figure 10 shows the throughput differentiation of DIFS-based scheme. Between 10 and 20 seconds, only two stations fairly share the channel because their aggregate rate is inferior to the maximum achievable throughput. When the third station starts transmitting, the channel capacity is lower than the total traffic and differentiation starts. Station 1 (Flow 1) obtains more bandwidth than stations 2 (Flow 2) and 3 (Flow 3), because it has the smallest DIFS.

4.2.2.2 Second Scenario: Increasing Number of Nodes

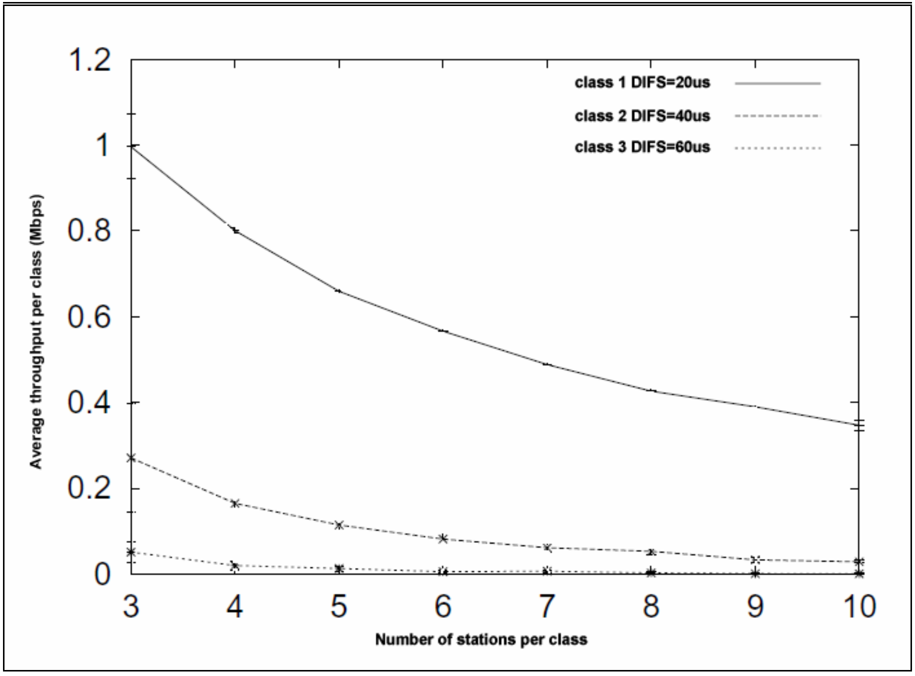

Figure 11. DIFS: Average throughput when increasing the number stations per class

Figure 11 shows the average throughput of stations that belong to one of the service classes, the same throughput differentiation is achieved with the presence of an increasing number of stations. However the throughput decreases with increase in the number of stations. This is mainly attributed to the shared nature of wireless channels.

4.2.2.3 Third Scenario: Introducing Mobility

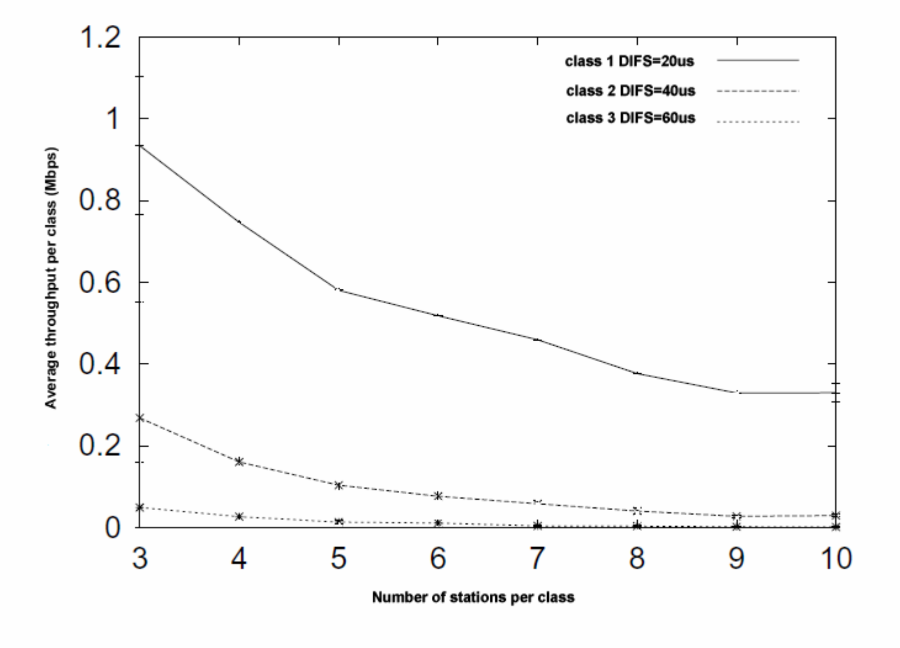

Figure 12. DIFS: Average throughput under Mobility

Figure 12 shows the average throughput obtained by stations within the same service class. Results show that the throughput differentiation takes effect even in the presence of mobility.

4.2.3 Backoff-Based Differentiation

In this Section we provide results obtained for backoff-based differentiation.

4.2.3.1 First Scenario

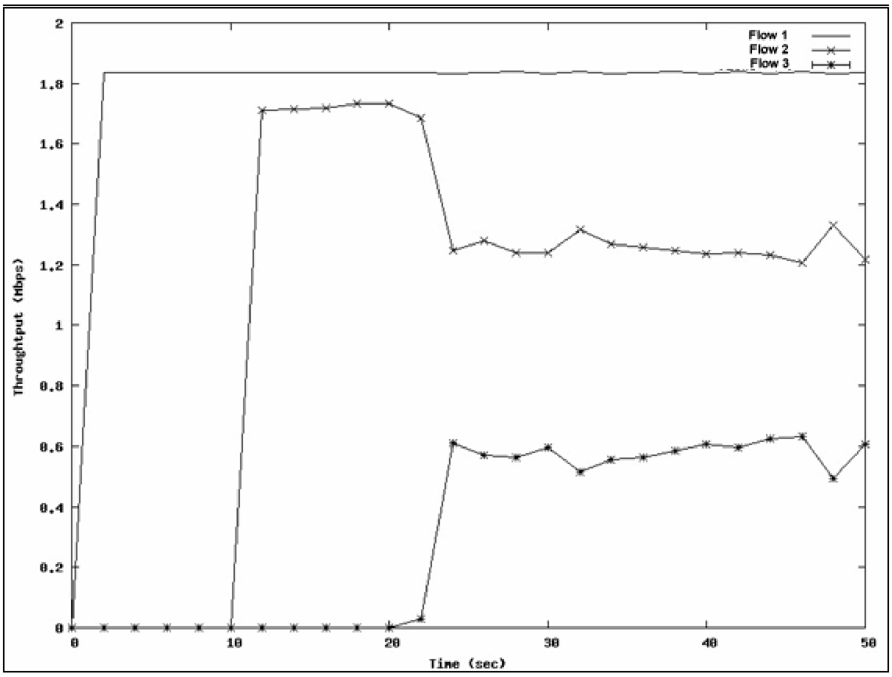

Figure 13. Throughput for Backoff -based Differentiation

Figure 13 shows clearly that the station (flow 1) with a smaller contention window interval have more bandwidth. Station 2 (flow 2) and 3 (flow 3) have their bandwidth decreased, hence making then share. However station 2 still has more bandwidth compared to 3 because it has a smaller contention window. The results clearly show that stations with a smaller CWmin value obtain a larger share of the channel capacity than the other stations.

4.2.3.2 Second Scenario: Increasing the Number of Nodes

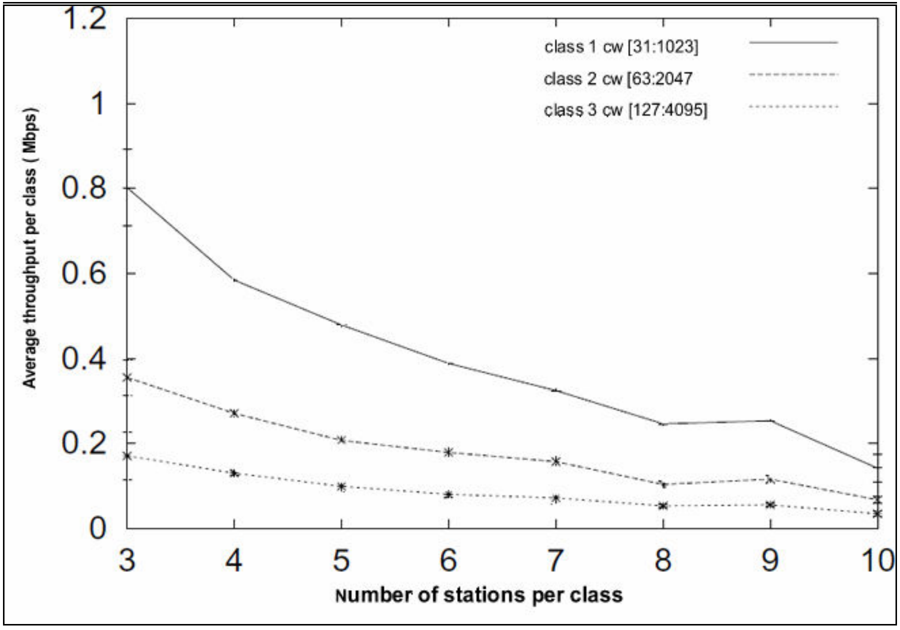

Figure 14. Backoff-Based: Average throughput when increasing the number of stations per class

Figure 14 shows the average throughput of stations that belong to one of the service classes, the same throughput differentiation is achieved with the presence of an increasing number of stations. However the throughput decreases with increase in the number of stations.

4.2.3.3 Third Scenario: Introducing Mobility

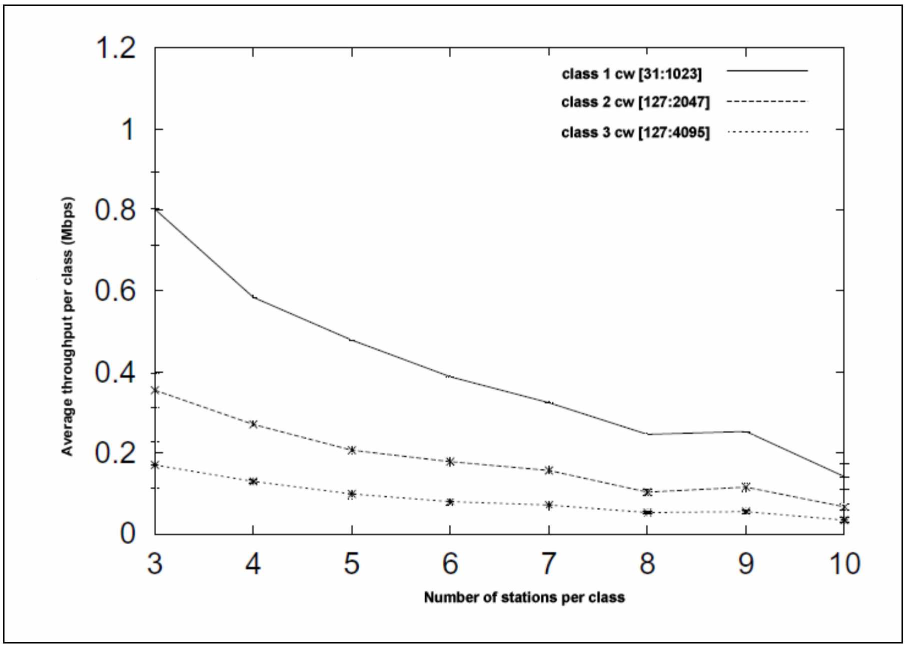

Figure 15. Backoff-based: Average throughput under mobility.