Spectrally Efficient Wireless Packet Data Transmission for Multimedia Services Provisioning

by

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This is to certify that I have examined this copy of a master's thesis by

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and have found that it is complete and satisfactory in all respects,
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To my grandfather, Ali Ekşim, died on November 8th 2002.

ABSTRACT

Efficient wireless packet data access is possible by exploiting the multi-user diversity using an opportunistic multiple access system that allocates system resources to one user at a time while employing adaptive coding and modulation. Based on this outcome, recently the IS-856 system was developed. A scheduling algorithm provides resource allocation in the IS-856 system, and its proper design is perhaps one of the most crucial aspects for ensuring good system performance. The thesis presents a number of such algorithms, five of which are novel. The proposed algorithms appear to have the best overall performance of achieving high system throughput without diverging much from the optimal latency performance. The thesis shows that the IS-856 system can easily be adjusted to provide a multitude of services, each with different QoS requirements. Extensive performance evaluations show that good system performance can be maintained in the multi-service scenario. The thesis also presents the means of providing multicast service provisioning in the IS-856 system.

The selection of the scheduling algorithm influences not only the system throughput but also the average delay exposed by users in between successive accesses to the system. The thesis proposes new access method, Two Users At A Time System, and its scheduling algorithms which decrease latency figures approximately 50%.

Present 3G carrier technologies cannot separately cover all the demands of the end-user in terms of coverage, bandwidth, quality of service (QoS) and cost. The 4G networks are heterogeneous networks that eliminate previous technologies drawbacks and contain large number of different access methods. Therefore, the thesis demonstrates new access methods are needed to combine some of the existing network topologies. These access methods provide wireless data connectivity for nomadic users when away from their offices and homes. The envisioned corporation increases the IS-856 network throughput more than 50%.

ÖZET

Verimli telsiz paket veri erişimini sağlamanın en iyi yolu çoklu-kullanıcı çeşitlemesinin kullanılmasıdır. IS-856 sistemi uyarlanmaz kodlama ve modülasyon türlerini kullanarak sistem kaynaklarını belli bir zaman diliminde sadece bir kullanıcıya ayırır. Bu sonuca dayanarak son zamanlarda IS-856 sistemi geliştirilmiştir. IS-856 sisteminde kaynak ayırımını çizelgeleme algoritması sağlar ve onun uygun tasarımı, iyi sistem performansının sağlanması için belkide en önemli yönlerinden birisidir. Tez , beş tanesi yeni olan çok sayıda algoritmayı açıklamaktadir. Önerilen algoritmalar optimal gecikme performanslarından uzaklaşmadan yüksek sistem iş çıkarma performansına ulaşarak en iyi toplam performansa sahip gözükmektedirler. Tez, IS-856 sisteminde her biri farklı hizmet niteliklerine gereksinim duyan çok sayıda servisi verilebileceğinin kolayca ayarlanabileceğini göstermiştir. Kapsamlı performans değerlendirmeleri iyi sistem performansının çoklu-servis senaryosunda da desteklendiğini göstermiştir. Ayrıca, tez çoğula iletim servisinin IS-856 sisteminde sağlanmasını açıklamıştır.

Seçilen çizelgeleme algoritması birbiri ardına sisteme giren kullanıcıların iş çıkarma yeteneğinden başka maruz kalınan ortalama gecikmelerinide etkiler. Tezin önerdiği yeni giriş metodu, Ayni Zamanli İki Kullanicili Sistem, ve onun çizelgeleme algoritmalari gecikme değerlerini yaklaşık olarak %50 azaltmaktadır.

Günümüzdeki 3. nesil taşıyıcı teknolojileri kapsama, bantgenişliği, hizmet nitelikliği ve maliyet açısından son kullanıcının bütün ihtiyaçlarını karşılayamamaktadır. 4. nesil ağlar önceki teknolojilerin dezavantajlarını ortadan kaldıran ve çok büyük sayıda giriş metodu içeren heterojen ağlardır. Bundan dolayı, tezde günümüzde olan bazı ağ topolojilerinin birleştirilmesinden oluşan yeni giriş metotları gösterilmiştir. Bu giriş metotları gezgin kullanıcıların ofislerinden ve evlerinden uzakta olduklarında telsiz veri bağlantısını sağlarlar. Öngörülen sistem, IS-856 ağ iş çıkarma gücünü %50`den fazla arttırır.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

16-QAM	16-state QAM
2G	Second Generation
2.5G	Enhanced Second Generation
3G	Third Generation
8-PSK	8-state PSK
ARQ	Automatic Retransmission Request
AWGN	Additive White Gaussian Noise
BER	Bit Error Rate
bps	Bits Per Second
C/I	Carrier-to-Interference Ratio
cdf	Cumulative Density Function
CDMA	Code Division Multiple Access
dB	Decibel
DS-CDMA	Direct-Sequence Code Division Multiple Access
FDM	Frequency Division Multiplexing
FDMA	Frequency-Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transform
FIR	Finite Impulse Response (filter)
GHz	Gigahertz
GSM	Global System for Mobile Communications
Hz	Hertz
HDR	High Data Rate
ICI	Intercarrier Interference
ISI	Intersymbol Interference
kbps	Kilo Bits Per Second
kHz	Kilohertz

LAN	Local Area Network
LFSR	Linear Feedback Shift Register
LOS	Line-Of-Side
Mbps	Mega Bits Per Second
MHz	Megahertz
MSK	Minimum Shift Keying
NLOS	Non-Line-Of-Sight
OFDM	Orthogonal Frequency Division Multiplexing
PER	Packet Error Rate
pdf	Probability Density Function
PN	Thermal Noise
PSK	Phase Shift Keying
QAM	Quadrature Amplitude Modulation
QPSK	Quaternary Phase Shift Keying
RF	Radio Frequency
RSP	Received Signal Power
SF	Shadow Fading
SIR	Signal-to-Interference Ratio
SNR	Signal to Noise Ratio
TDMA	Time Division Multiple Access
UIP	Unrecovered Interference Power
URF	Uncorrelated Rayleigh Fading
USP	Unrecovered Signal Power
WLAN	Wireless Local Area Network

Chapter 1

INTRODUCTION

1.1 Background

Compared to its wired counterpart, the mobile environment introduces unique design challenges to the communications system engineer. The most prominent of such challenges is the time-varying characteristics of the communication channel. The presence of fading, multipath, shadowing and path losses all amount to significant variations of the channel gain over time [1]. The mobility as well as the carrier frequency dictates the rate of the channel fluctuations around its mean. In communication theory, traditionally, the channel fading is viewed as a source of unreliability that has to be mitigated. This is because, inherent in the design parameters of most of the communication systems of the past and the present is the goal of providing voice transmission. The voice service does not allow for exploitation of the channel variations due to its delay intolerant nature.

Digital voice communication in wireless systems of today requires the transmission of a pre-defined data rate at all times, regardless of the state of the wireless channel. The date rate is dictated by the vocoder in use. The constant data rate results in the use of non-adaptive coding and modulation schemes in voice communications. For acceptable voice quality, such systems are designed to maintain a desired signal-to-noise ratio (SNR) level at all fading states of the channel. This SNR level corresponds to a tolerable error probability for the vocoder in use. In CDMA based voice communication systems, the maintenance of the target SNR is accomplished by means of power control. The constant data rate, constant SNR requirements of voice communication constrains the design of communication systems.

One performance measure for the communications systems has traditionally been the system capacity. Due to the traditional voice-centric nature of the multi-user communication system design, most papers in the literature have associated the number of users that can be serviced simultaneously to the capacity. When the system merely provides a single service that is voice, this may be an appropriate measure. However, a rigorous definition of capacity stems its roots back to information theory. The information theoretic capacity of a communication system is the maximum transmission rate that still enables error-free communication [4]. In a system that provides a multitude of data services, the total number of bits that the system can provide to all its subscribers per unit time, namely, the system throughput is directly related to the information theoretic capacity of the system.

Today, voice communication remains to be the dominant application in wireless systems. Its status as a premier application is expected to continue for several years to come. However, it has also become evident that the explosive growths of the Internet and the wireless mobile communications will very likely create new opportunities for wireless networks to support various multimedia and data applications. In this light, wireless system standards of today are being modified to provide for more efficient data transmission over the wireless media. Standardized 2.5G and first phase 3G systems such as EGPRS, W-CDMA and cdma2000 attempt to provide such capability by evolving the air interface (both in terms of data rates and capacity) of 2G systems. In this evolution, the existing 2G resource allocation mechanisms as well as physical layer design parameters for voice are further optimized and carried over, and as a result, voice services are well supported. However, support for delay tolerant data services such as Internet access are still inadequate. The inefficiency stems from the fact that even though resource requirements for packet data are significantly different and in certain aspects at odds with that of voice, voice-centric techniques are universally applied in all of the above mentioned standards due to their 2G legacy. This points to the need for a new, and optimized, set of techniques unique to packet data transmission.

Spectrum is a very expensive resource that needs to be efficiently utilized by the wireless communication systems. It is known that the single-user communication scheme that maximizes the data throughput in a time-varying channel is one that incorporates adaptive coding, modulation and power control in response to the variations in the communication channel [5]. This is referred to as water filling in time where more of the system resources are allocated to the user's communication needs when the channel is good and less when the channel is bad. Relative to the constant data rate designs of current systems, this system provides a greater throughput for the same average transmission power. However, this increase in the throughput comes at the expense of a resultant stochastic behavior at the information data rate. Therefore, inherent in this outcome is that, when transmitted information is tolerant to delay, it is possible to increase the throughput of the system significantly by making use of the time-varying characteristics of the wireless system, provided that the channel characteristics are continuously tracked and accurately and speedily fed back to the transmitter.

For multi-user wireless systems, exploitation of the wireless channel for throughput maximization comes in the form of a new multiple access scheme developed by Knopp and Humblet in 1995 [6]. It is proved that to maximize the throughput of the multi-user communication system in a frequency-flat time-varying channel, one needs to allocate all of the system resources in a time-multiplexed fashion to only one user at a time. At any given time, the system needs to schedule the user with the best channel characteristic [7]. This result is intuitive when one considers the fact that the time-varying wireless channel characteristics observed by different users are independent from one another. Therefore, the likelihood of finding all users experiencing deep fades at the same time is very slim as illustrated in Figure 1.1 for the case of two users. In fact, for a reasonably populated wireless system, at a given time, it is quite likely to find at least one user experiencing a channel level exceeding its own average. If such a user is successfully identified for each time instance and is scheduled for service at that specific time, it is clear that much higher spectral efficiencies will be observed; even higher than those observed for the case of the AWGN channel. We refer to this scheme as the opportunistic multiple access scheme. Clearly, in opportunistic multiple access, the scheduled users need to employ adaptive coding and modulation as well to adaptively change their transmission rates according to the channel they observe. The opportunistic multiple access scheme paves the way to the exploitation of a new type of diversity, labelled in the literature as multi-user diversity. In multi-user diversity, the larger the dynamic range of the channel fluctuations, the higher the channel peaks and thus the higher the diversity gain, provided that the channel information is fed back accurately and instantaneously. Similarly, the larger the number of users in system, the more likely it is to find a user experiencing a high channel peak, once again increasing the system throughput. Thus, unlike the traditional multiple access schemes of FDMA, TDMA or CDMA where the

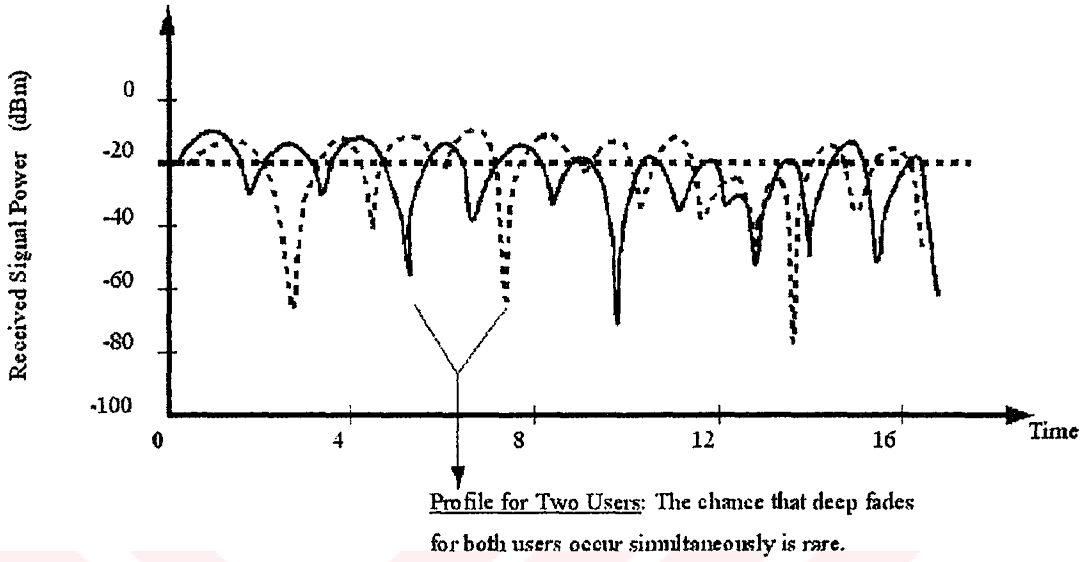

Figure 1.1: Time-Varying Wireless Channels Observed by Two Independently Located Users

system spectral efficiency is independent of the number of users, the opportunistic multiple access provides for a better spectral efficiency as the number of users in the system increases [8]. It should be noted here that, similar to the adaptive coding, modulation and power control outcome of the single-user case, the one user at a time outcome of the multi-user communication system requires delay tolerance of the information transfer.

Realizing the potential of wireless data transmission, standards bodies have begun to incorporate the findings of [5], [6] and [8] into the 3G-downlink air interface specifications in Europe and the US. High Speed Downlink Packet Access (HSDPA) which is part of W-CDMA Release 5 [9] developed by the Third Generation Partnership Project (3GPP) and 3G 1xEV-DO [10, 11] as well as 3G 1xEV-DV [12, 13] developed by the Third Generation Partnership Project 2 (3GPP2) are three outcomes of this attempt. The 1x prefix in 1xEV-DO and 1xEV-DV stems from its use of 1 times the 1.2288 Mcps spreading rate of the North American 2G standard, IS-95. EV emphasizes that it is an evolutionary technology building on and improving on the current technology. The DO suffix stands for Data Only and indicates that 1xEV-DO is designed primarily for efficient packet data transfer. The DV suffix on the other hand, stands for Data and Voice and indicates that 1xEV-DV is designed for simultaneous voice and efficient packet data transfer on the same spectrum.

The North American solution of 1xEV-DO comes in the form of a new wireless standard: IS-856 [10]. Here, packet data service is offered on a separate, dedicated spectrum where opportunistic multiple access is employed. Key in the operation of the IS-856 system is the scheduler. The scheduler decides how to adaptively perform resource allocation, and thus, is directly responsible for the throughput and delay performance of the packet data system. Even though the algorithm that selects the user with the best channel conditions at a given time is optimum in maximizing the system throughput; it is not fair across the user population. In a cellular environment it is quite likely that users far away from the serving base station will consistently experience inferior channel conditions relative to the users closer to the base station. In this case, the optimum algorithm will never provide service to the far away users allowing for user starvation in the system. Therefore, practical scheduling algorithms need to strive for fairness while attempting to increase the system throughput by effectively utilizing the multi-user diversity. The Proportional Fair (PF) scheduling algorithm, proposed by Qualcomm, has been the most visible of such algorithms in the literature [27]. However, IS-856 with the Proportional Fair algorithm inherently assumes that all users subscribe to the same type of service, and thus, have no priority over one another. Investigation of the possibility of using the PF algorithm to enable spectrally efficient "multi-service" and "multicast" packet data provisioning on the downlink of the IS-856 system is an open research area. Another prominent scheduling algorithm from the literature is the Exponential Rule [28]. The main thrust of this thesis lies in the development of fair scheduling algorithms that provides high system throughput. We also develop extensions to existing and newly proposed scheduling algorithms to allow for multimedia and multicast services provisioning. In this thesis, we provide extensive comparisons amongst various scheduling algorithms in various operating environments and gain insights into the operational details. In this light, we show that in a cellular environment where users experience different Dopplers, the Proportional Fair algorithm fails to be as fair as the Exponential Rule. However, the Exponential Rule, in return, results in a slightly inferior system throughput.

The mobile industry has largely bet its future on data, believing the ongoing decline in the revenue for voice services can be offset by selling customers new services based on data and multimedia. It has invested heavily in developing, and acquiring spectrum for, new technologies that offer higher data speeds and the capacity to support them for many customers. The IS-856 standard is a significant step in this direction. However, when wide area coverage is not needed, a much cheaper alternative that provides even higher data rates is available; the wireless local area networks (WLANs). The WLANs based on the IEEE 802.11x technologies have gained very significant attention recently. It is predicted that in Western Europe alone the number of WLAN hotspots will to grow to more than 32,500 locations by 2007, generating total revenue of $1.4 billion. Thus, it is obvious that cellular and WLAN networks will co-exist in many geographical areas. Predicting this outcome, in this thesis, we investigate the inter-operation of an IS-856 system with isolated WLAN hotspots within the larger cells. We assume that the cellular network operates in cooperation with those of the WLANs and that these networks provide assistance to one another in increasing the overall system performance. Specifically, in this thesis we investigate the performance of the IS-856 system when it is allowed to make use of the WLAN networks within its cells and observe significant gains. Clearly, WLANs may assist the IS-856 system only as long as their users' energy levels are not seriously decapitated.

1.2 Motivation

The wireless data requirements are often at odds with those of voice resulting in inefficient information transfer in current wireless systems for non-voice applications. It is known that in a frequency flat fading channel, the optimal resource allocation is one where adaptive coding and modulation is used together with the opportunistic multiple access scheme. Unfortunately, this optimal algorithm is not practical since it causes user starvation in a cellular structure. Schedulers that provide fairness across the user domain whereas providing higher spectral efficiencies are necessary in this case to obtain high data rates. The system, standardized in North America as the IS-856 standard uses all the optimal solutions mentioned above but also allows for practical scheduling algorithms to perform resource allocation.

At the same time, the wireless data applications of tomorrow are likely to require a multitude of Quality of Service (QoS) requirements and such schedulers need to take these requirements into account as well. This thesis is concerned with the investigation and development of scheduling algorithms that provide resource allocation for a highly spectrally efficient wireless packet data system. In this light, exhaustive study and performance evaluation of the published scheduling algorithms have been conducted. The performances of these schedulers are compared in terms of the system throughput as well as average experienced user latency. While the former measure indicates the spectral efficiency, the latter provides means for comparing the level of fairness. Based on the intuition gained from the study of the various schedulers, a number of new scheduling algorithms are developed in this thesis as well.

The envisioned upcoming wireless data applications may be unicast or multicast. In current wireless systems, the multicast applications are still being served by using the unicast set-up repeatedly. This is so, despite the fact that unlike wired networks, the wireless system needs to utilize the bandwidth very effectively. Using the unicast set-up to provide multicast services becomes less and less efficient as the number of multicast service subscribers increases. In this thesis, we provide means of resource allocation to enable true multicast operation for the physical layer of the wireless system.

Alone with the aforementioned facts, after the economic downturn in the telecommunications industry post 3G spectrum licensing, the mobile industry has largely bet its future on data for fourth generation, believing that the ongoing decline in the revenue for voice services can be offset by selling customers new services based on data and multimedia. The IS-856 standard, which only aims to provide wireless packet data access is a significant step in this direction. This is because, perhaps for the first time, the technology for a major wireless standard has been developed without thinking of voice as the main application. However, it has also become a reality that when wide area coverage and high-speed mobility are not needed, the wireless local area networks (WLANs) in the form of IEEE 802.11x or HIPERLAN provide a significantly cheaper alternative to systems such as IS-856. For this reason, the WLAN technology has recently gained a significant interest throughout the world. It predicted that in Western European alone the number of WLAN hotspots will to grow to more than 32,500 locations by 2007, generating total revenue of $1.4 billion. Thus, it is becoming more and more obvious that cellular and WLAN networks will co-exist in many geographical areas. Predicting this outcome, in this thesis, we investigate the interoperation of an IS-856 system with isolated WLAN hotspots within the larger cells. We assume that the cellular network operates in cooperation with those of the WLANs and that these networks provide assistance to one another in increasing the overall system performance. Specifically, in this thesis we investigate the performance of the IS-856 system when it is allowed to make use of the WLAN networks within its cells and observe significant gains. Clearly, WLANs may assist the IS-856 system only as long as their users' energy levels are not seriously decapitated.

1.3 Contributions of Thesis

The following list is an outline of the major contributions presented in this thesis.

- A detailed performance evaluation of the current IS-856 system is performed using a number of the scheduling algorithms from the literature. Realistic wireless channel models are used in this evaluation and the system performance in terms of the throughput and average observed user latency are used as a performance metrics.

- The IS-856 system, which is aimed to provide wireless packet data access does not explicitly provide multi-service support. Such a support has to be accomplished by developing appropriate scheduling algorithms. The multi-user capable scheduling algorithms have been developed in this thesis for the first time.

- Up until now, the support for multicast operation has not been provided by any of the wireless communication systems' lower OSI layers. In this thesis, such support is developed and investigated for the IS-856 system.

- New scheduling algorithms for spectrally efficient as well as practical resource allocation for the IS-856 have been developed in this thesis. The developed algorithms maintain the delicate balance of achieving high spectral efficiencies all the while ensuring some level of fairness across the subscribed users.

- This thesis envisions that fourth generation wireless systems will need to enable cooperation among the WLANs and improved versions of today's 3G systems. It is shown in this thesis that, it is possible to achieve significant gains in the IS-856 system performance if the WLAN hotspots inside the cellular layout cooperate. Such a cooperation should be carefully planned to ensure that during the cooperation, a pre-defined level energy consumption threshold of the WLAN subscribers is never crossed.

1.4 Presentation Outline

Most scientific work related to begins with the explanation of employed network structure. The specifics of the IS-856 Forward Channel Structure is overviewed in Chapter 2. A literature survey of the scheduling algorithms appropriate for use in the IS-856 system has been given in Chapter 3. Chapter 3 also provides the descriptions of the proposed scheduling algorithms and the motivation behind their characteristics. In Chapter 4, detailed descriptions are given on the developed performance evaluation platform that is used to investigate the performance of the IS-856 system with the schedulers of Chapter 3. The performance results are also given in Chapter 4. Chapter 5 discusses the modifications to the IS-856 system if two users, instead of one, were allowed to find service in the IS-856 system simultaneously. Simple scheduling algorithms have been proposed for this scenario and performance results have been showed in this chapter. Chapter 6 provides for a literature survey on the wireless local area networks. Chapter 7 discusses the envisioned WLAN and IS-856 cooperation and the resultant performance increase. Finally, Chapter 8 contains a compendium of the principal results presented in this thesis. Suggestions for further research are listed.

Chapter 2

IS-856 FORWARD LINK

While deploying, modernizing, or maintaining telecommunication networks, the structure of the system should be exactly known by the network design engineers, otherwise, operators will lose capacity, bandwidth, and money. For this reason, this chapter explains the IS-856 airlink, and mainly forward link structure and its operations like encoding, modulation, and scrambling.

As stated before, to maximize the system throughput for delay tolerant data transmission over a frequency-flat fading channel, one needs to employ multi-user diversity by allocating the system resources to only one user at a time per unit time. Within a given unit time period, the user with the best channel characteristics needs to be scheduled for service. Furthermore, the scheduled user needs to employ adaptive coding and modulation with fine granularity to achieve the throughput optimal water-filling over time. This scheme requires perfect and instantaneous knowledge of the channel characteristics at the transmitter so that the scheduling is done correctly and the scheduled user can pick the appropriate coding and modulation scheme.

The theoretically optimal scheme outlined above is not realizable in practice due to a number of reasons. First, practicality dictates that there needs to be a finite duration of time interval and not a time instant for a user to utilize the system resources. Second, the number of adaptive modulation and coding schemes one can deploy in a system will have to be finite, causing quantization losses in the water-filling in time argument. Third, one cannot always guarantee the frequency-flat fading characteristics of the transmission media. Fourth, the necessary channel characteristic feedback will inevitably be delayed, sometimes in error, but more importantly, incomplete. Only a quantized version of the information will be fed back in practice. Last but not least, allocation of system resources to the user with the best channel characteristics at a given time may result in user starvation. This is because, in a cellular environment, it is very likely that users closer to cell boundaries will observe inferior channel characteristics than users closer to the serving base stations. If such users were to be static, or near static, then the optimal system of the previous paragraph would end up servicing only the users closer to the base stations, thereby starving the users at the cell boundaries for service. Thus, a notion of fairness needs to be added to the scheduling rule in a practical system. However, one needs to make sure that this added fairness does not cause large deviations from the optimal achievable system throughput.

With these ideas in mind, Qualcomm proposed the High Data Rate (HDR) system in 1999 [11] which was later standardized as IS-856 [10]. The IS-856 has been practiced in KOREA for the first time in the world, can render good performance and economical benefits [42].

2.1 The IS-856 Airlink

The IS-856 airlink is projected for packet data optimization [43]. It is spectrally efficient and provides 7.4 Mbps/cell 3 sectors combined forward peak throughput with a single CDMA frequency carrier. The most important assumption of IS-856 is that voice and data have very different requisites. There will be unskillfulness anytime the two services are combined. Hence, the IS-856 design requires a distinct CDMA carrier.

The IS-856 waveform holds 100% compatibility with IS-95/1x from the RF point of view [43]. The IS-856 waveform utilizes the same 1.228Mcps chip rate, link budgets, network plans, and RF designs on both Access Terminals and infrastructure. Moreover, transmitting voice and data on different carriers is more appropriate for both voice and data: Two important advantages are easiness of system software development and preventing difficult load-balancing tasks.

The IS-856s forward link employs power expeditiously. When the data rate is the received by access terminal, the Access Network which provides wide-area high-rate data access on a wireless CDMA channel to a collection of static or mobile access terminals [46], is updated according to received data. Then, the scheduler selects a user and the system transmits a data to a single user at any instant. Instead of using power control, the rate control characteristic helps the IS-856 Access Point to always transmit at full power achieving very high peak rates for users that are near the base station.

The Access Terminal and the Access Point decide each user's forward link data. The Access Terminal evaluates the pilot signal power, and continually calls for a harmonious data rate related to the channel conditions. The Access Point transmits data via the forward link at exactly the highest rate that the users channel condition can support at any instant [43].

The nature of data applications is emphatically asymmetric. A much higher forward data rate is needed from the access point than that yielded by the access terminal in the reverse direction [11]. With this information, IS-856 provides asymmetric data rates on the forward and reverse links. IS-856s forward peak data rate is 2.457 Mbps/sector and the reverse peak data rate is 153.6 kbps/sector.

The IS-856 airlink is designed for providing high performance average data throughput with only 1.25 MHz of spectrum. The average forward link throughput in a 3-sector cell is shown in the Table 2.1. The average reverse link is 600 kbps/cell [43]. The IS-856 performance simulation results can be found in the literature [47, 49, 50]. In [42], rather than the simulation, the mathematical approached is used to determine the average sector throughput of IS-856 and the expected average throughput is 683 Kbps in the classical urban environment. The simulation results in Chapter 4 verify the given estimated average throughput in [42].

2.2 The Forward Link Structure

The overall Forward Link IS-856 channel structure is shown in Figure 2.3 and Figure 2.4 depicts the IS-856 Channel hierarchies. As explained previous section, the Pilot Channel, the Medium Access Control Channel (MAC), the Forward Traffic Channel and Control Channel, are the time-division-multiplexed channels that form the IS-856

Environment & Antenna Type	Forward Link
Pedestrian-Single Receive	3.1 Mbps/cell
Pedestrian-Dual Receive	4.0 Mbps/cell
Low Speed Mobile-Single Receive	1.3 Mbps/cell
Low Speed Mobile-Dual Receive	2.5 Mbps/cell
High Speed Mobile-Single Receive	2.0 Mbps/cell
High Speed Mobile-Dual Receive	3.1 Mbps/cell

Table 2.1: 3-Sector Cell Forward Link Average Throughput

forward link. The MAC Channel includes 3 subchannels. The Traffic Channel usually carries user physical layer packets. The main function of Control Channel carries control messages, and it may also carry user traffic. Every forward link channel is farther disintegrated into code-division-multiplexed quadrature Walsh channels [44, 45, 43].

Physical layer packets can be created by encoding the Forward Traffic Channel and Control Channel data. After encoding processing, the output shall be scrambled before sending the channel interleaver. After channel interleaver, the output shall be fed into the modulator which applies QPSK, 8-PSK, and 16-QAM according to requested data rate. After modulation, the symbols can be repeated and punctured, and then de multiplexed to constitute 16 in-phase and quadrature pairs of parallel streams. Every parallel stream can be covered with different 16-ary Walsh function. Walsh Code streams can be aggregated to obtain a single in-phase and a single quadrature stream to sustain chip rate of 1.2288 Mhz. Finally, the yielded chips are time-division multiplexed with the preamble, Pilot Channel, and MAC Channel chips.

Physical layer packets can be transmitted in 1, 2, 4, 8, or 16 slots. When more than one slot is allocated for the transfer of information data, the transmit slots use a 4-slot interlacing to perform a simple hybrid ARQ operation [51]. Here, the transmit slots of a physical layer packet are separated by three intervening slots, and slots of other physical layer packets are transmitted in the slots between those transmit slots.

If a positive acknowledgement is received on the reverse link ACK Channel before all of the allocated slots have been transmitted, the remaining slots of the physical layer packet need not be transmitted and the next allocated slot may be used for the first slot of the next physical layer packet transmission. In this case, the net effective transmission rate of the physical layer packet is increased.

The 307.2 kbps can be transmitted in 2 or 4 slots. The Figure 2.1 and Figure 2.2 demonstrate multislot interlacing for a 307.2 kbps with DRCLength of one slot. The 307.2 kbps packets transmitted 4 slots with 3 slot intervals. In Figure 2.1, normal physical layer packet termination is showed. The nominal 4 slots are received by the access terminal. On the other hand, Figure 2.2 represents early physical layer packet termination. In this case, ACK message sends after 3 physical layer packets received, and the remaining packet does not transmit.

The *ForwardTrafficCompleted* indication message sends if all slots have transmitted or ACK has received. The Control Channel modulation features are the same as that of the Forward Traffic Channel, uses only 76.8 kbps or 38.4 kbps for data transmission. The modulation parameters for the Forward Traffic Channel and the Control Channel are illustrated in Table 2.2. In addition to modulation parameters, The Table 2.2 shows the Forward Traffic Channel varying data rate from 38.4 kbps to 2457.6 kbps. The Table 2.3 illustrates the MAC Channel modulation parameters. The transmitted slot has traffic and control data is called an idle slot.

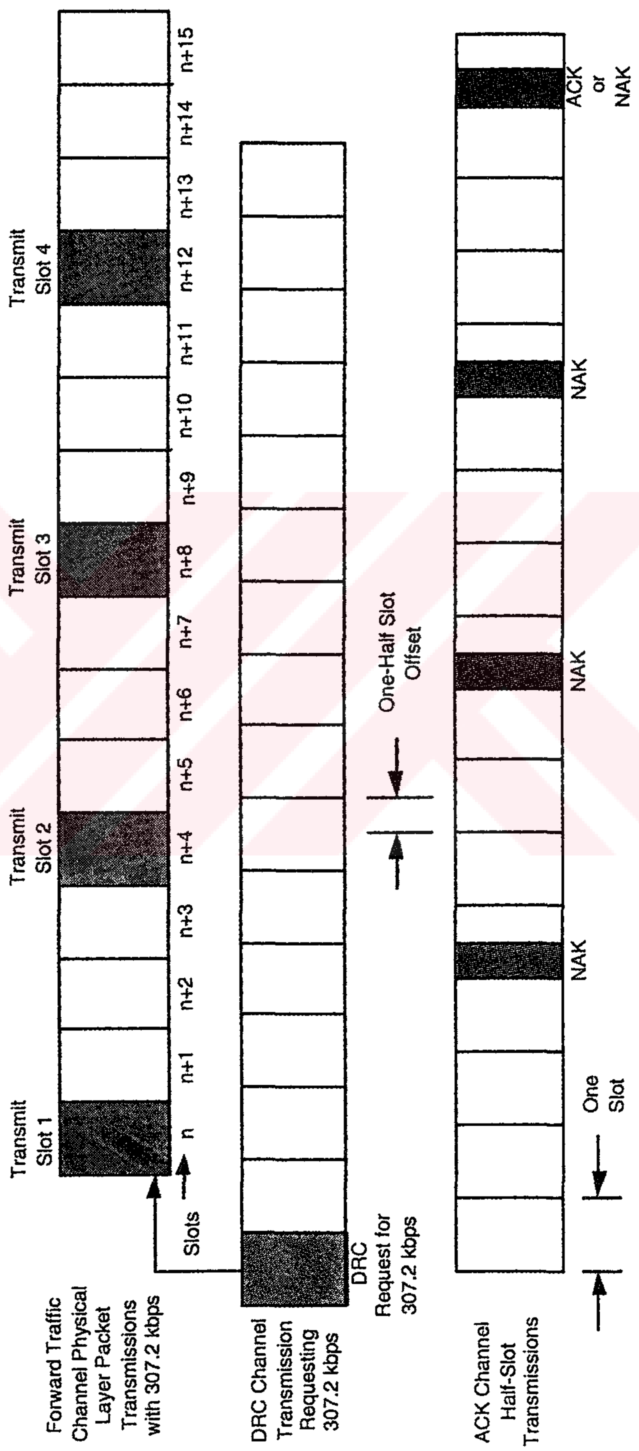

Figure 2.1: Multislot Physical Layer Packet with Normal Termination

Data Rate (kbps)	Slots	Bits	Code Rate	Modulation Type	TDM Chips (Preamble, Pilot MAC,Data)
38.4	16	1024	1/5	QPSK	1024,3072 4096,24576
76.8	8	1024	1/5	QPSK	512,1536 2048,12288
153.6	4	1024	1/5	QPSK	256,768 1024,6144
307.2	2	1024	1/5	QPSK	128,384 512,3072
614.4	1	1024	1/3	QPSK	64,192 256,1536
307.2	4	2048	1/3	QPSK	128,768 1024,6272
614.4	2	2048	1/3	QPSK	64,384 512,3136
1228.8	1	2048	1/3	QPSK	64,192 256,1536
921.6	2	3072	1/3	8-PSK	64,384 512,3136
1843.2	1	3072	1/3	8-PSK	64,192 256,1536
1228.8	2	4096	1/3	16-QAM	64,384 512,3136
24576	1	4096	1/3	16-QAM	64,192 256,1536

Table 2.2: Modulation Parameters for the Forward Traffic Channel and the Control Channel

Parameter	RPC Channel	DRCLock Channel	RA Channel
Rate (bps)	600 x (1-1/DRCLockPeriod)	600/(DRCLockLength x DRCLockPeriod)	600/RABLength
Bit Repetition Factor	1	DRCLockLength	RABLength
Modulation (Channel)	BPSK (I or Q)	BPSK (I or Q)	BPSK (I)
Modulation Symbol Rate	2400 x (1-1/DRCLockPeriod)	2400/DRCLockPeriod	2400
Walsh Cover Length	64	64	64
Walsh Sequence Repetition Factor	4	4	4
PN Chips/Slot	256	256	256
PN Chips/Bit	256	256 x DRCLockLength	256 x RABLength

Table 2.3: Modulation Parameters for the MAC Channel

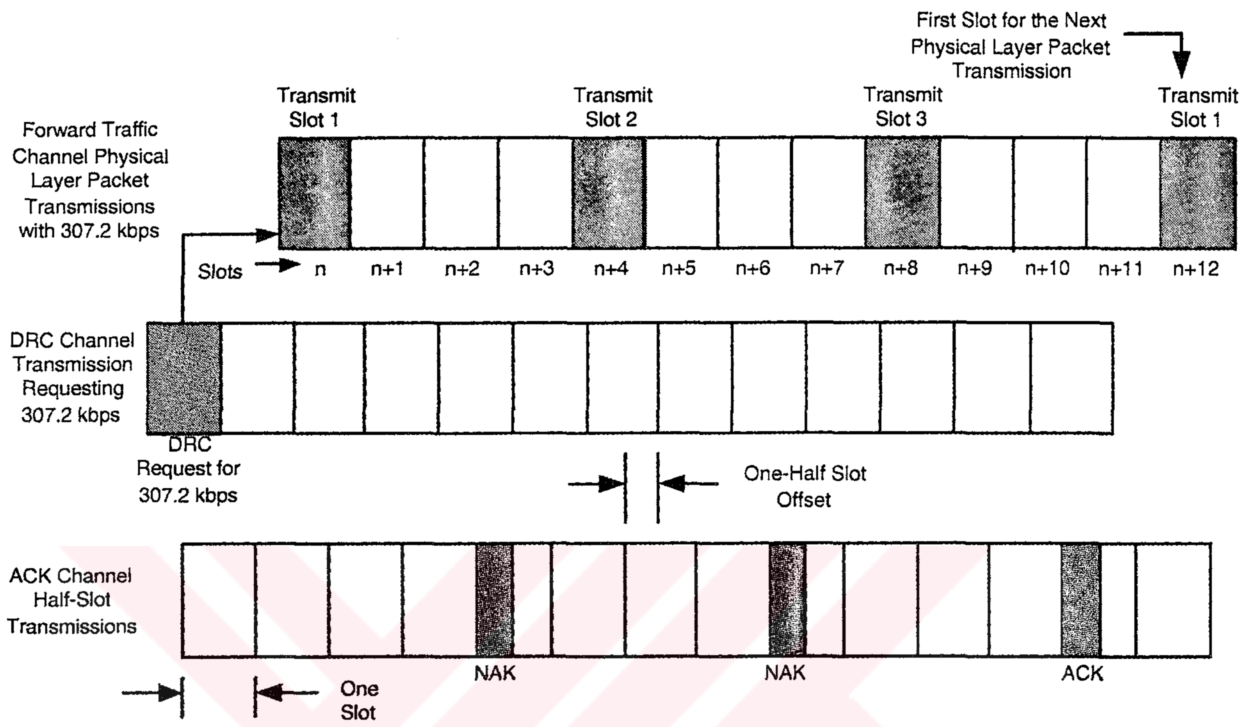

Figure 2.2: Multislot Physical Layer Packet with Early Termination

2.2.1 Forward Link Channels

Pilot Channel

Pilot Channel is actually unmodulated signal at the center of every half slot. Each pilot burst has duration of 96 chips that can be transmitted at all times with full power. The functions of pilot channel are initial acquisition, phase recovery, timing recovery, symbol combining, and channel estimate for the purpose of rate adaptation. Pilot Channel includes all-'0' symbols transmitted with in-phase component and Walsh cover 0 assigned for Pilot Channel [45, 44].

Forward MAC Channel

The MAC Channel on the other hand, consists of power control information and channel activity information to aid the reverse link operation. Each MAC Channel

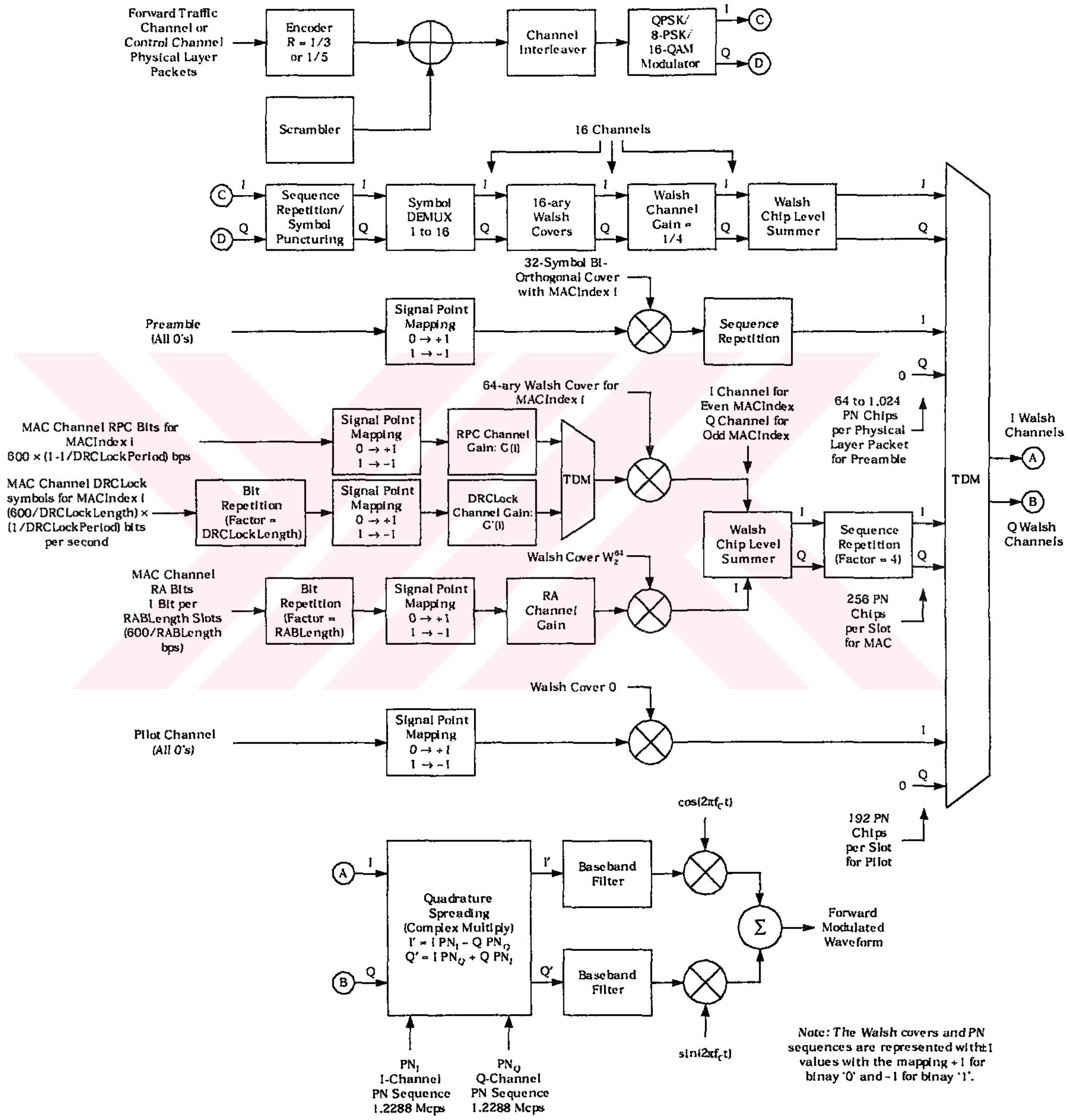

Figure 2.3: IS-856 Forward Channel Structure

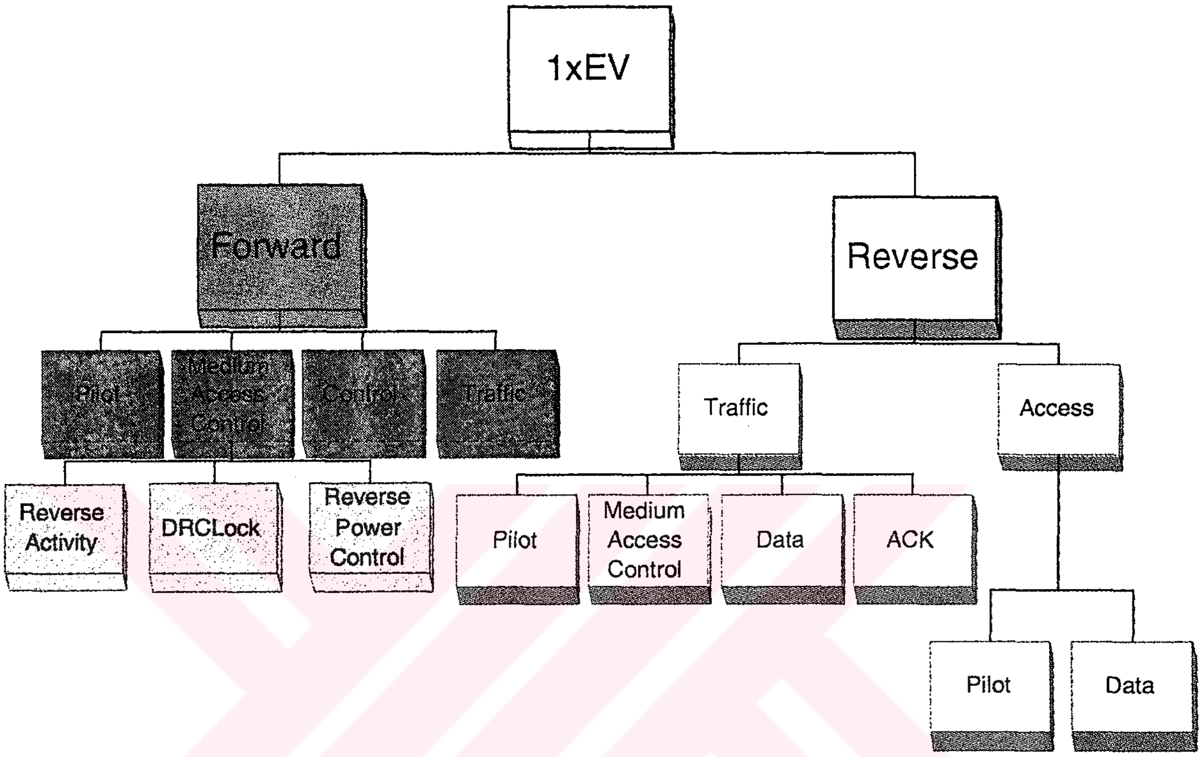

Figure 2.4: IS-856 Channel Hierarchies

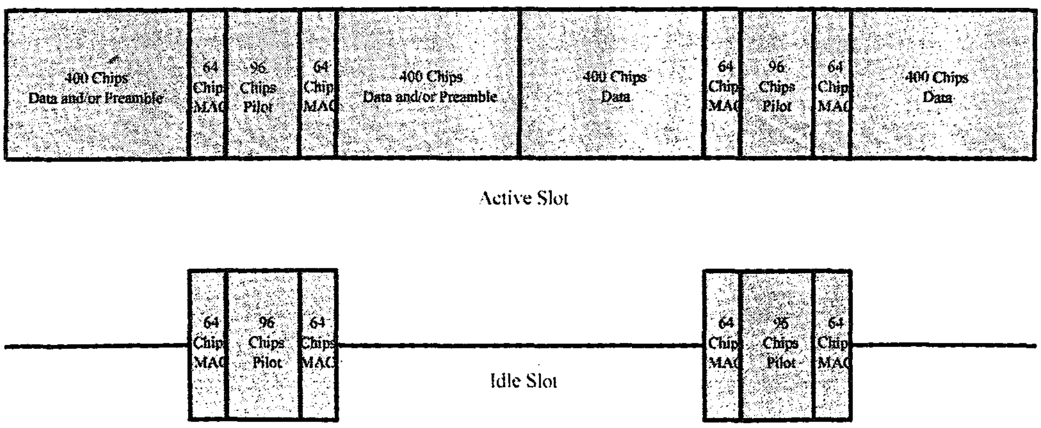

Figure 2.5: IS-856 Forward Link Slot Structure

MACIndex	**MAC Channel Use**	**Preamble Use**
0 and 1	Not Used	Not Used
2	Not Used	76.8 kbps Control Channel
3	Not Used	38.4 kbps Control Channel
5-63	Available for RPC and DRCLock Channel Transmissions	Available for Forward Traffic Channel Transmissions

Table 2.4: MAC Channel and Preamble Use Versus MACIndex

symbol is modulated on one of 64 64-ary Walsh codewords. The MAC symbol Walsh covers are transmitted four times per slot in bursts of 64 chips each. Bursts are transmitted immediately preceding and immediately following each of the pilot bursts in a slot. If the base station has no information to transmit, an idle slot needs to be transmitted which still includes the pilot and the MAC bursts. The IS-856 forward link slot structure is shown in Figure 2.5. The Forward MAC Channel includes Walsh Channels, which are orthogonally covered, and BPSK modulated on either in-phase or quadrature phase. Every MAC Channel can be extracted by assigned MACIndex value that is changing between 0 to 63. The MACIndex i the attributed for Walsh function can be found

$$\begin{array}{l} W^{64}_{i/2} \text{ for } i\text{=0, 2,...., 62} \\ W^{64}_{(i-1)/2+32} \text{ for } i\text{=1, 3,...., 63} \end{array} \tag{2.1}$$

where i is the MACIndex value [45]. Even numbered MACIndex values can be designated in-phase if MACIndex value is even, otherwise, odd numbered MACIndex values are quadrature. If the base station has no information to transmit, an idle slot needs to be transmitted which still includes the pilot and the MAC bursts. The IS-856 forward link slot structure is shown in Figure 2.5.

The *Reverse Power Control* (RPC) Channel can be employed for the transmission of the RPC bits to the access terminal. The RPC Channel and the DRCLock Channel can be time-division multiplexed. The RPC data rate can be 600 x (1-

1/DRCLockPeriod) bps. The RPC bit transmits every slot T with

$$\text{(T - FrameOffset)} \mod \text{DRCLockPeriod} \neq 0. \tag{2.2}$$

The *DRCLockChannel* is used for transmission of DRCLock bits to the access terminal. The multiplexed DRCLock Channel and RPC Channel can be transmitted on the same MAC Channel. The DRCLock data rate can be 600/(DRCLockLength x DRCLockPeriod) bps. The DRCLock bit transmits every slot T with

$$\text{(T - FrameOffset)} \mod \text{DRCLockPeriod} = 0. \tag{2.3}$$

The function of the *Reverse Activity* (RA) Channel is to transmit Reverse Activity Bit (RAB) stream with MACIndex 4. The data rate of RA Channel is 600/RABLength bps. Every RA bit in each slot can be echoed to constitute four symbols per slot for transmission [45].

Forward Traffic Channel

The Forward Traffic Channel, which transmits the information data within a slot, is a packet-based, variable-rate channel and rates varying from 38.4 kbps to 2.4576 Mbps. The information data is encoded in blocks called physical layer packets. 4 physical layer packet sizes are defined in IS-856, 1024 bits, 2048 bits, 3072 bits and 4096 bits.

A preamble presents in the Forward Traffic and in the Control Channel to aid synchronization of variable data rate. The preamble sends only in-phase part with all symbols is equal to 0. The preamble can be enclosed by 32-chip biorthogonal sequence and this sequence repeated as many times as needed which is related to transmission scheme. The preamble repetition is illustrated in Table 2.5.

2.2.2 Encoding

Generally data applications can support a wide range of delays; data frame sizes are longer than voice frames. Increasing the frame length has important advantages

Data Rate (kbps)	Slots	32-Chip Preamble Sequence Repetitions	Preamble Chips
38.4	16	32	1024
76.8	8	16	512
153.6	4	8	256
307.2	2	4	128
614.4	1	2	64
307.2	4	4	128
614.4	2	2	64
1228.8	1	2	64
921.6	2	2	64
1843.2	1	2	64
1228.8	2	2	64
2457.6	1	2	64

Table 2.5: Preamble Repetition

because it decreases overhead and results in increased system efficiency. There are more subtle advantages to increasing the frame size, most notably the efficient use of Turbo codes. Both voice and data in modern communications systems use coding techniques to reduce error rates to make the communications channel more robust. Turbo coding becomes practical for encoding the data stream. Turbo coding with large frames size significantly improves performance by allowing the use of lower RF power while still achieving the same error rate. In fact, Turbo coding allows the communication channel to perform close to the Shannon limit [48].

The channel conditions determine data rate and number of slots used to transmit. If channel conditions are not convenient, a lower data rate with more slots is used. Additional time slots transmit redundant information. If poor channel conditions present, the coding rate provides increased redundancy to help assure packets are decoded when received by the mobile [48].

The modulation rates, 1/3 and 1/5, are utilized to encode the Traffic Channel packets. The tail bits are discarded before the Turbo Encoder as explained in section 2.2.2. At the output of the encoder, the tail bits that are generated the internal operations of the encoder, are added to maintain total number of output symbols. Forward encoding method is explained in Figure 2.6 and encoder specifications can be found in Table 2.6.

Turbo Encoder

The turbo encoder uses systematic, recursive, convolutional encoders connected in parallel. The recursive convolutional codes are called constituent codes. The turbo encoder utilizes the transfer function of the constituent code

$$G(D) = [1 \; \frac{n_O(D)}{d(D)} \; \frac{n_1(D)}{d(D)}] \tag{2.4}$$

where $d(D) = 1 + D^2 + D^3$, $n_O(D) = 1 + D + D^3$, and $n_1(D) = 1 + D + D^2 + D^3$ [45].

The output symbols are generated by the encoder demonstrated in Figure 2.7. At the beginning, constituent encoder registers are adjusted to zero, and the switch positions changes with clock. When bits come to the turbo encoder, the 6-tail bits are discarded.

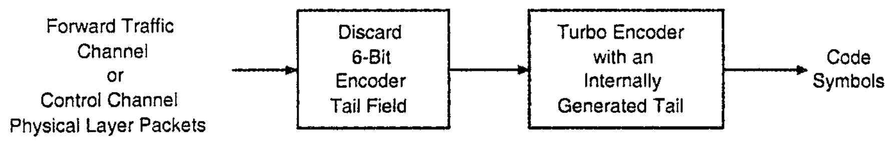

Figure 2.6: Forward Link Encoder

The number of remaining bits are called N_{turbo}. The turbo encoder outputs can be generated N_{turbo} times clocking the constituent encoders and puncturing as showed in Table 2.6.

Turbo Interleaver

The turbo interleaver is part of the turbo encoder. The turbo interleaver writes the entire sequence of turbo interleaver input bits consecutively into an array at a sequence of addresses, and then the overall sequence is read out from a sequence of addresses which are depicted in Figure 2.8. Tables 2.7−2.8 are showed turbo interleaver parameter and turbo interleaver lookup table definition, respectively [45].

2.2.3 Scrambling

Before modulation, encoder outputs can be scrambled. The scrambling sequence can be achieved by a 17-tap linear feedback shift register with a generator sequence of h(D)=D^{17} + D^{14} + 1, as shown in the Figure 2.9. The initial state of the shift register is $[1111111r_5r_4r_3r_2r_1r_0d_3d_2d_1d_0]$. The $r_5r_4r_3r_2r_1r_0$ bits illustrate the 6-bit preamble MACIndex value as seen in Table 2.4. The $d_3d_2d_1d_0$ bits can be determined

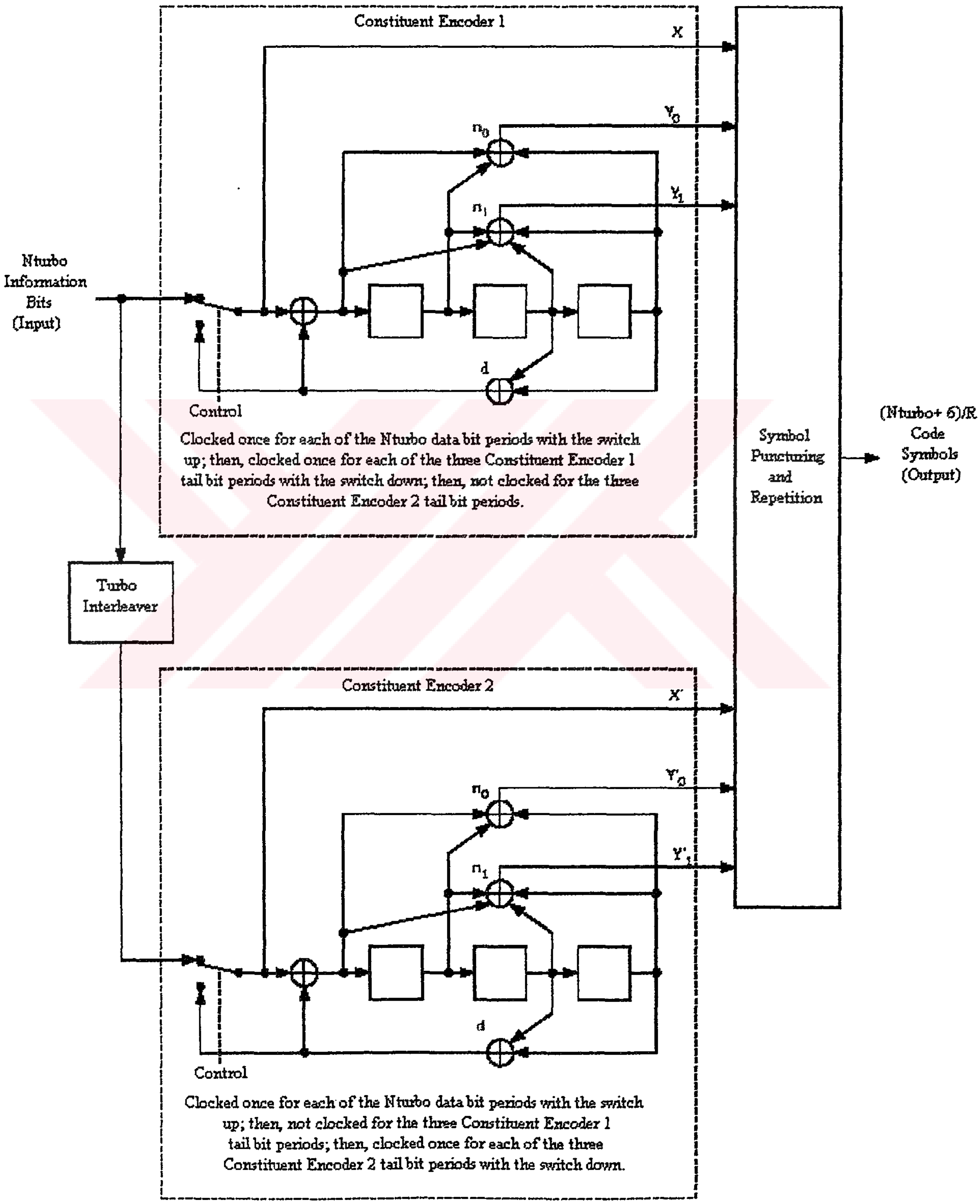

Figure 2.7: Turbo Encoder

Data Rate (kbps)	Slots	Bits	Turbo Encoder Input Bits	Code Rate	Turbo Encoder Output Symbols
38.4	16	1024	1018	1/5	5120
76.8	8	1024	1018	1/5	5120
153.6	4	1024	1018	1/5	5120
307.2	2	1024	1018	1/5	5120
614.4	1	1024	1018	1/3	3072
307.2	4	2048	2042	1/3	6144
614.4	2	2048	2042	1/3	6144
1228.8	1	2048	2042	1/3	6144
921.6	2	3072	3066	1/3	9216
1843.2	1	3072	3066	1/3	9216
1228.8	2	4096	4090	1/3	12288
2457.6	1	4096	4090	1/3	12288

Table 2.6: Parameters of the Forward Link Encoder

Physical Layer Packet Size	Turbo Interleaver Block Size N_{turbo}	Turbo Interleaver Parameter n
1024	1018	5
2048	2042	6
3072	3066	7
4096	4090	7

Table 2.7: Turbo Interleaver Parameters

Table Index	**n=5 Entries**	**n=6 Entries**	**n=7 Entries**
0	27	3	15
1	3	27	127
2	1	15	89
3	15	13	1
4	13	29	31
5	17	5	15
6	23	1	61
7	13	31	47
8	9	3	127
9	3	9	17
10	15	15	119
11	3	31	15
12	13	17	57
13	1	5	123
14	13	39	95
15	29	1	5
16	21	19	85
17	19	27	17
18	1	15	55
19	3	13	57
20	29	45	15
21	17	5	41
22	25	33	93
23	29	15	87
24	9	13	63
25	13	9	15
26	23	15	13
27	13	31	15
28	13	17	81
29	1	5	57
30	13	15	31
31	13	33	69

Table 2.8: Turbo Interleaver Lookup Table Definition

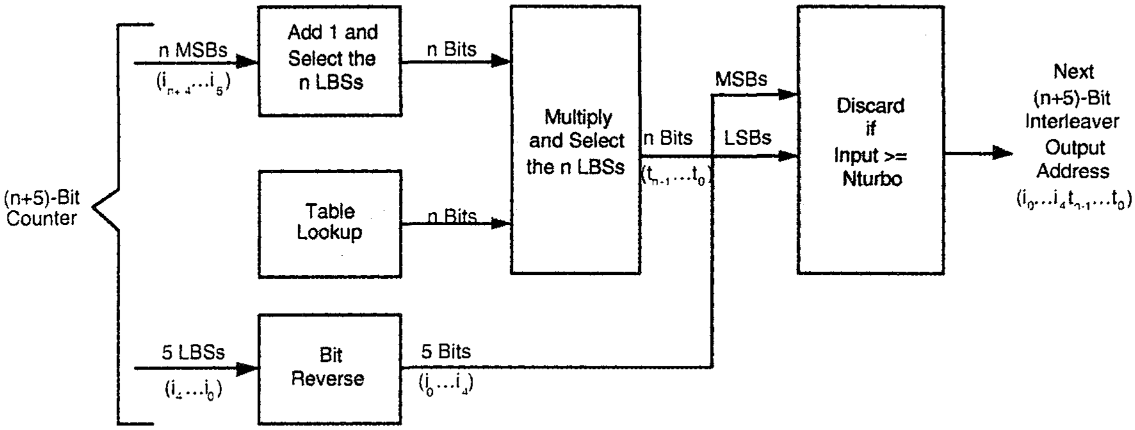

Figure 2.8: Turbo Interleaver Output Address Calculation Procedure

by the data rate as shown in Table 2.9. Each encoder output can be XOR'd with the scrambling sequence to produce scrambled encoded bit.

2.2.4 Channel Interleaving

The channel interleaving includes two operations: *Symbol Reordering*, and *Symbol Permuting*. Symbol Reordering generates the scrambled turbo encoder data and tail output symbols with the rate-1/5 encoder and the rate-1/3 encoder.

The rate-1/5 encoder outputs uses following steps. First of all, the scrambled data and tail turbo encoder output symbols can be demultiplexed into five groups referred

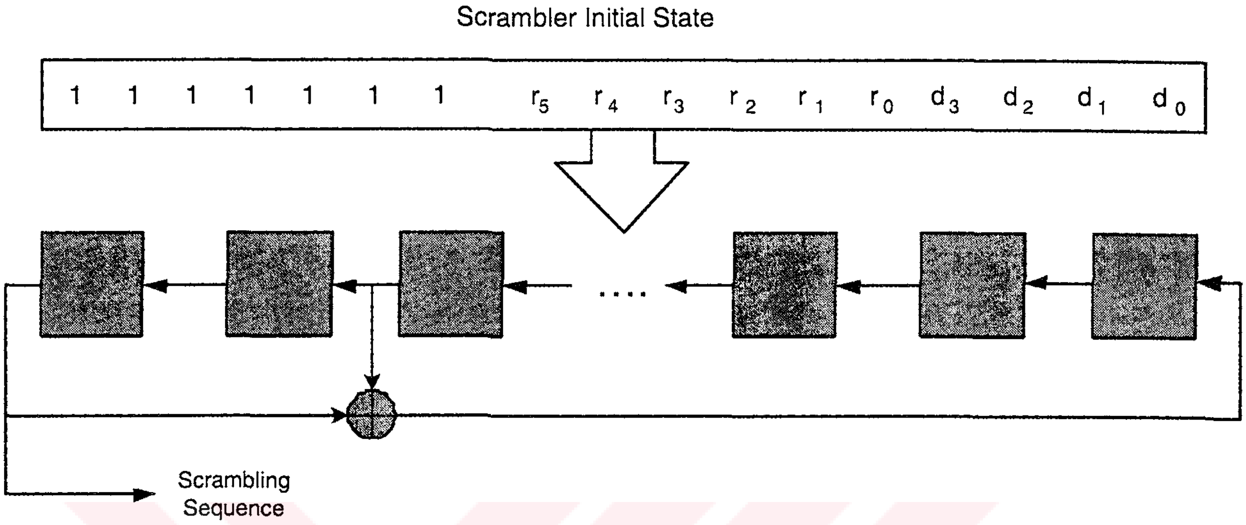

Figure 2.9: Symbol Scrambler

Data Rate (kbps)	Slots per Physical Layer Packet	d_3	d_2	d_1	d_0
38.4	16	0	0	0	0
76.8	8	0	0	1	0
153.6	4	0	0	1	1
307.2	2	0	1	0	0
307.2	4	0	1	0	1
614.4	1	0	1	1	0
614.4	2	0	1	1	1
921.6	2	1	0	0	0
1228.8	1	1	0	0	1
1228.8	2	1	0	1	0
1843.2	1	1	0	1	1
2457.6	1	1	1	0	0

Table 2.9: Parameters Controlling the Scrambler Initial State

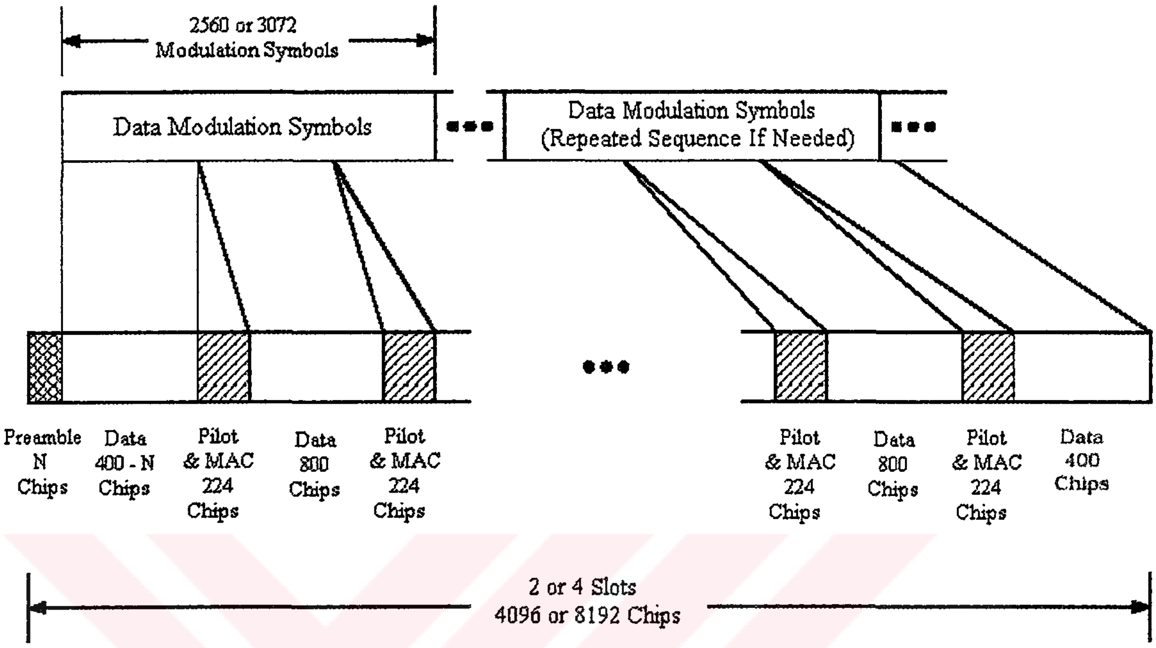

Figure 2.10: Preamble, Pilot, MAC, and Data Multiplexing for the Multiple-Slot Cases with Data Rates of 153.6, 307.2, 614.4, 921.6, and 1228.8 kbps

U, V_0, V_1 , V_0', and V_1', respectively. The scrambled encoder output symbols shall be sequentially distributed from the U sequence to the V_1' sequence. Then, the U, V_0, V_1 , V_0', and V_1' sequences can be arranged the following group: $UV_0V_1V_0'V_1'$.

The rate-1/3 encoder outputs uses following steps. First, the scrambled data and tail turbo encoder output symbols can be demultiplexed into three groups referred U, V_0, V_0', severally. The scrambled encoder output symbols shall be sequentially distributed from the U sequence to the V_0' sequence. Then, the U, V_0, and V_0' sequences can be arranged the following group: UV_0V_0'. Table 2.10 shows the order of the symbols out of the turbo encoder and their mapping to demultiplexer output sequences.

After reordering process, the obtained symbols can be commuted in three separate bit-reversal interleaver blocks with rate-1/5 coding and in two separate blocks with rate-1/3 coding. The permuter input blocks include the U sequence of symbols, the V_0 and V_0' sequence of symbols which denoted as V_0/V_0' , and, with rate-1/5 coding, the V_1 sequence of symbols followed by the V_1' sequence of symbols that denoted as

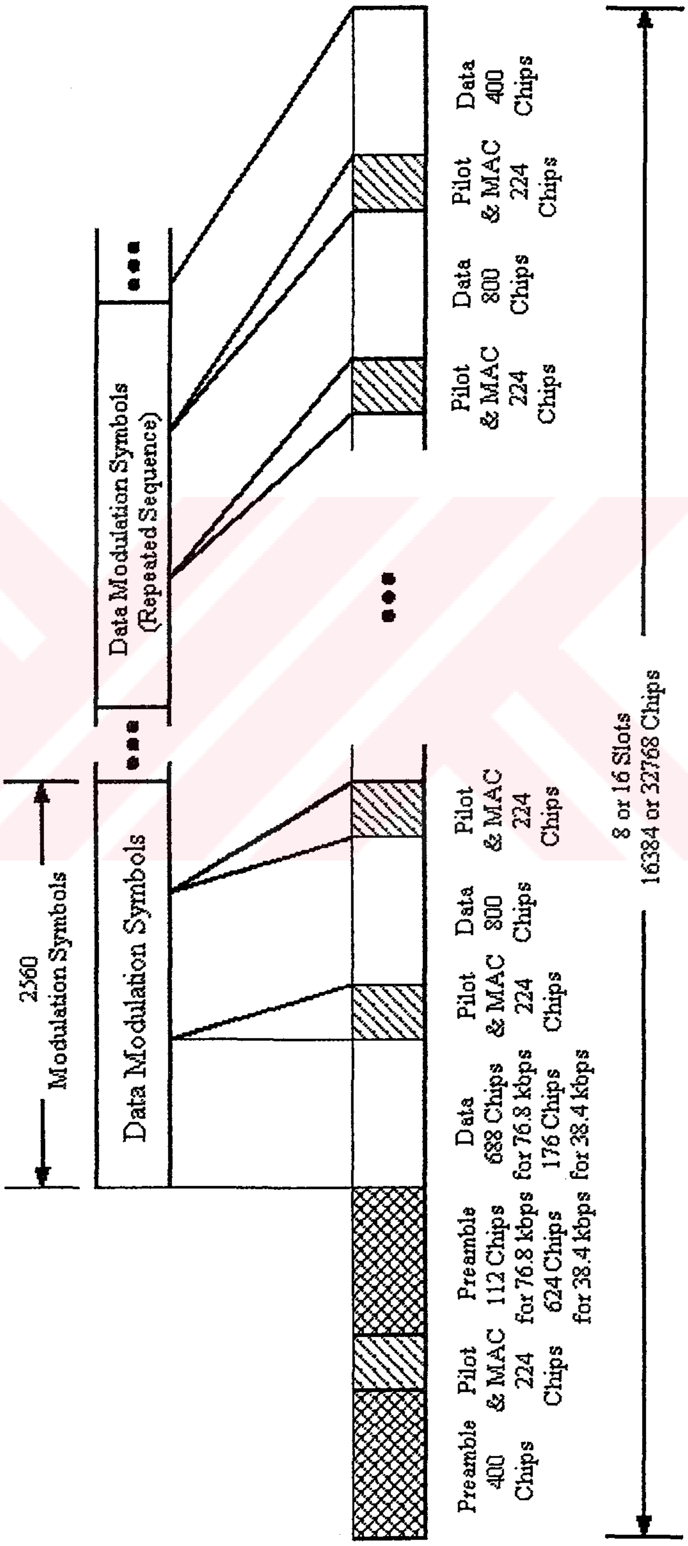

Figure 2.11: Preamble, Pilot, MAC, and Data Multiplexing with Data Rates of 38.4 and 76.8 kbps

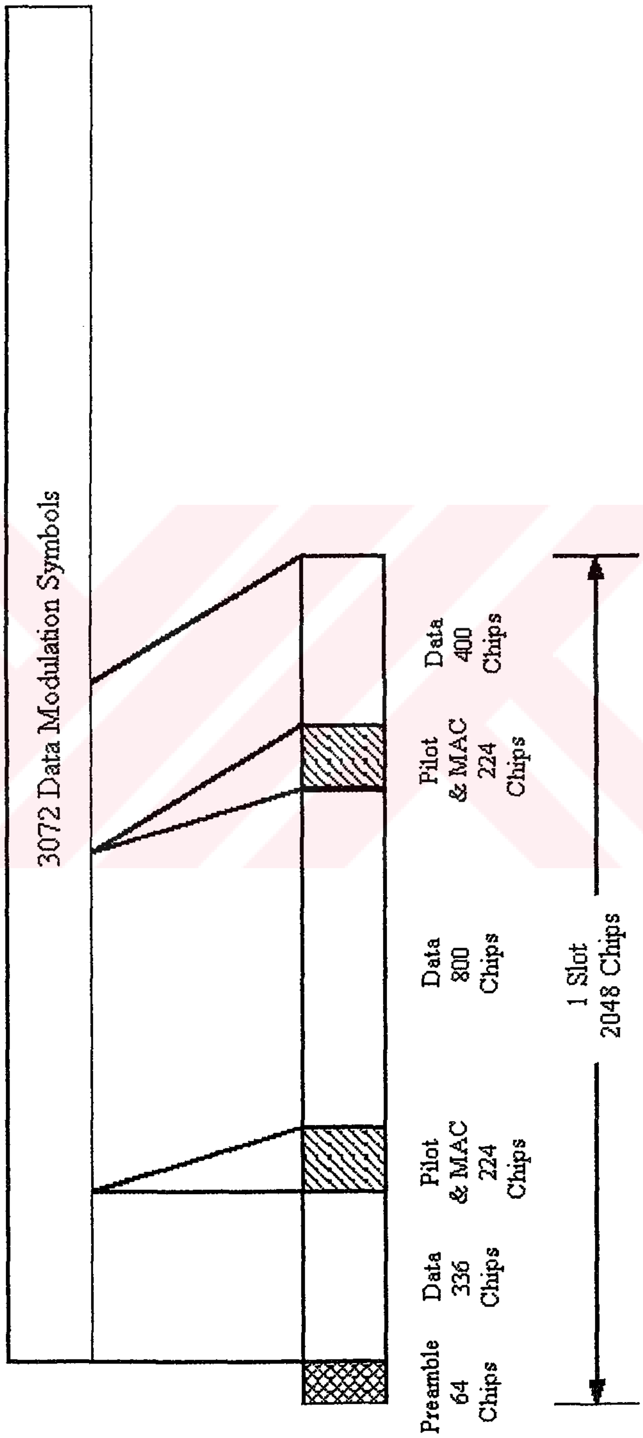

Figure 2.12: Preamble, Pilot, MAC, and Data Multiplexing for the 1-Slot Cases with Data Rates of 1.2288, 1.8432, and 2.4576 Mbps

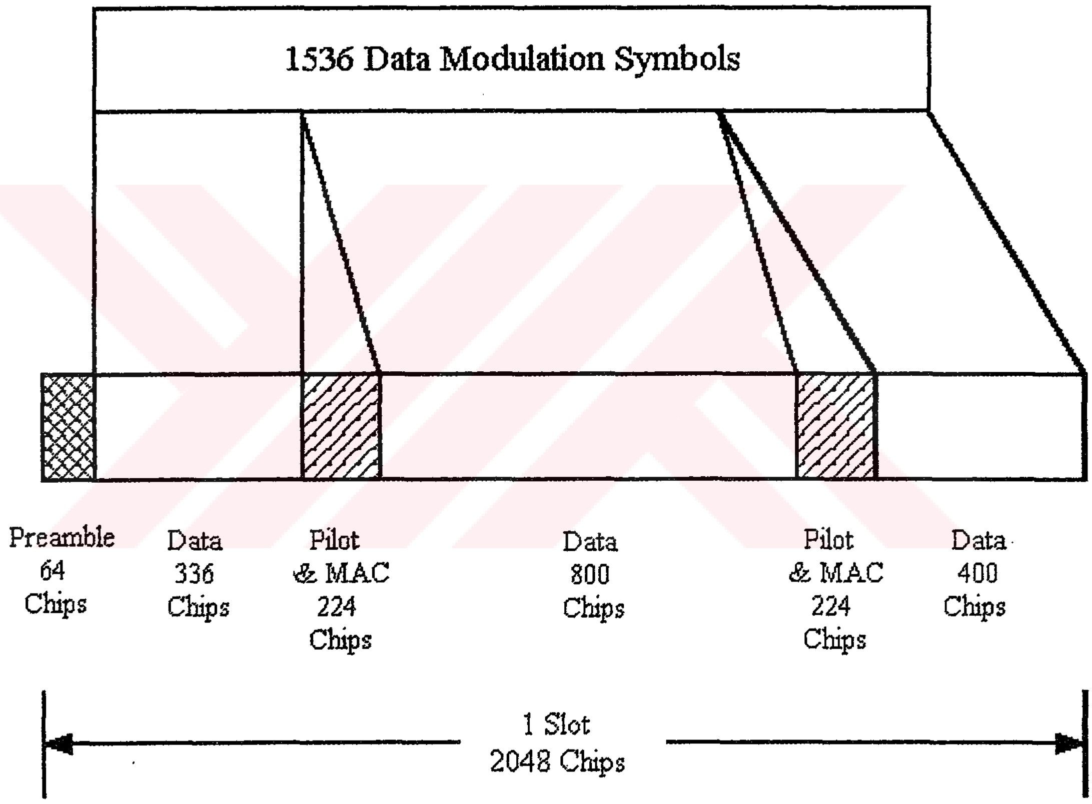

Figure 2.13: Preamble, Pilot, MAC, and Data Multiplexing for the 1-Slot Case with a Data Rate of 614.4 kbps

Type of Sequence	Symbol Sequence R=1/5	Symbol Sequence R=1/3
Turbo Encoder Data Output Sequence	$XY_0Y_1Y_0'Y_1'$	XY_0Y_0'
Turbo Encoder Constituent Encoder 1 Tail Output Sequence	$XXY_0Y_1Y_1$	XXY_0
Turbo Encoder Constituent Encoder 2 Tail Output Sequence	$X'X'Y_0'Y_1'Y_1'$	$X'X'Y_0'$
Demultiplexer Output Sequence	$UV_0V_1V_0'V_1'$	UV_0V_0'

Table 2.10: Scrambled Turbo Encoder Output and Symbol Reordering Demultiplexer Symbol Sequences

V_1/V_1'. The Channel Interleaver parameters are depicted in Table 2.11 [45].

2.2.5 Modulation

After interleaver, the in-phase and quadrature values can be employed to a modulator. The modulator produces QPSK, 8-PSK, or 16-QAM modulation symbols, according to the data rate.

QPSK Modulation

The channel interleaver output symbols can be formed to build QPSK modulation symbols. As depicted in Table 2.11, interleaver output symbols, x(2i), and x(2i+1), i=0,1,....,M-1, can be mapped to complex modulation symbols $m_{I(i)}$, $m_{Q(i)}$ as seen in Table 2.12 where D is equal to $1/\sqrt{2}$. QPSK modulator signal constellation is shown in Figure 2.14.

Physical Layer Packet Size	**U Block Interleaver Parameters K, M**	V_0/V_0' **and** V_1/V_1' **Block Interleaver Parameters K, M**
1024	2, 512	2, 1024
2048	2, 1024	2, 2048
3072	3, 1024	3, 2048
4096	4, 1024	4, 2048

Table 2.11: Channel Interleaver Parameters

s_1 x(2k+1)	s_0 x(2k)	$m_I(k)$	$m_Q(k)$
0	0	D	D
0	1	-D	D
1	0	D	-D
1	1	-D	-D

Table 2.12: QPSK Modulation Table

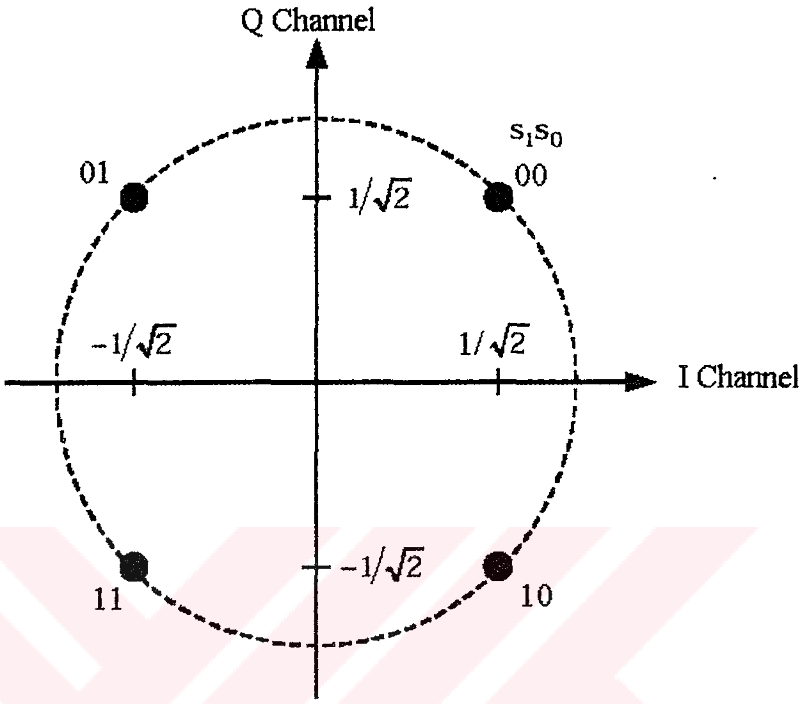

Figure 2.14: Signal Constellation for QPSK Modulation

8-PSK Modulation

When the physical layer packet size is 3072 bits modulator employs 8-pSK modulation. Interleaver output symbols, x(3i), x(3i+1), and x(3i+2) where i=0,1,....,M-1 as shown in Table 2.11 can be represented by complex modulation symbols $m_{I(i)}$, $m_{Q(i)}$ as explained in Table 2.13 where C is equal to 0.9239 and S equals to 0.3827. Figure 2.15 demonstrates 8-PSK signal constellation.

s_2 x(3k+2)	s_1 x(3k+1)	s_0 x(3k)	$m_I(k)$	$m_Q(k)$
0	0	0	C	S
0	0	1	S	C
0	1	1	-S	C
0	1	0	-C	S
1	1	0	-C	-S
1	1	1	-S	-C
1	0	1	S	-C
1	0	0	C	-S

Table 2.13: 8-PSK Modulation Table

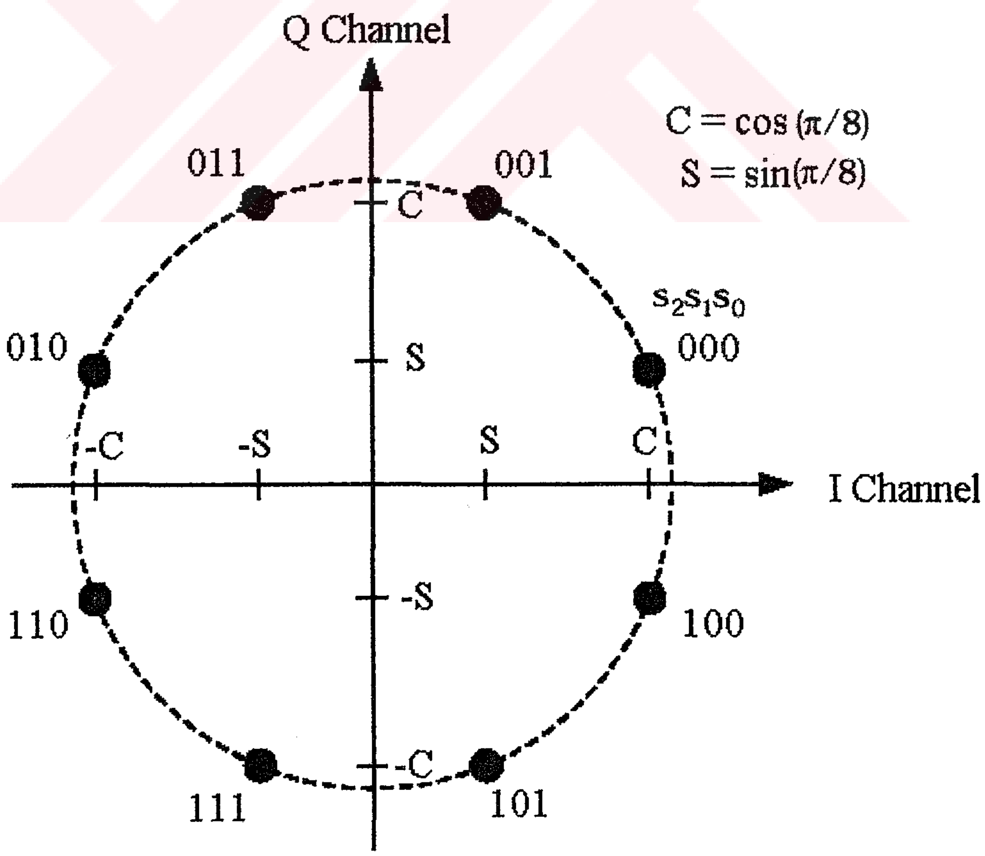

Figure 2.15: Signal Constellation for 8-PSK Modulation

s_3 x(4k+3)	s_2 x(4k+2)	s_1 x(4k+1)	s_0 x(4k)	$m_I(k)$	$m_Q(k)$
0	0	0	0	3A	3A
0	0	0	1	3A	A
0	0	1	1	3A	-A
0	0	1	1	3A	-A
0	1	0	0	A	3A
0	1	0	1	A	A
0	1	1	1	A	-A
0	1	1	0	A	-3A
1	1	0	0	-A	3A
1	1	0	1	-A	A
1	1	1	1	-A	-A
1	1	1	0	-A	-3A
1	0	0	0	-3A	3A
1	0	0	1	-3A	A
1	0	1	1	-3A	-A
1	0	1	0	-3A	-3A

Table 2.14: 16-QAM Modulation Table

16-QAM Modulation

If the physical layer packet size is 4096 bits, the modulator applies 16-QAM modulation. The interleaver output symbols, x(4i), x(4i+1), x(4i+2), and x(4i+3), where i=0,1,....,M-1 as illustrated in Table 2.11 can be mapped out into complex modulation symbols $m_{I(i)}$, $m_{Q(i)}$ as in Table 2.14 where A is 0.3162. Figure 2.16 shows 16-QAM signal constellation.

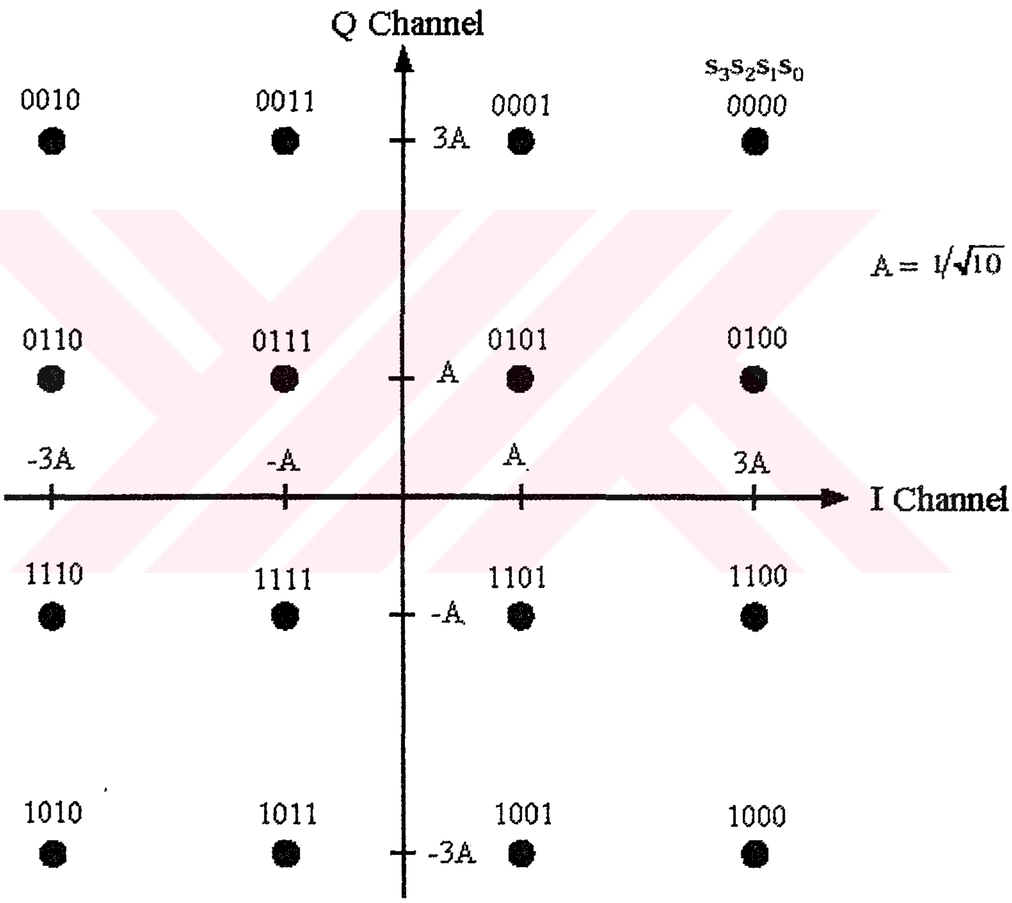

Figure 2.16: Signal Constellation for 16-QAM Modulation

Data Rate (kbps)	No. of Slots	No. of Bits	No. of Modulation Provided	No. of Modulation Symbols Needed	Number of Full Sequence Transmissions	No. of Modulation Symbols in Last Partial Transmissions	Code Rate	Repetition Factor
38.4	16	1024	2560	24576	9	1536	1/5	9.6
76.8	8	1024	2560	12288	4	2048	1/5	4.8
153.6	4	1024	2560	6144	2	1024	1/5	2.4
307.2	2	1024	2560	3072	1	512	1/5	1.2
614.4	1	1024	1536	1536	1	0	1/3	1
307.2	4	2048	3072	6272	2	128	1/3	2.04
614.4	2	2048	3072	3136	1	64	1/3	1.02
1228.8	1	2048	3072	1536	0	1536	2/3	1
921.6	2	3072	3072	3136	1	64	1/3	1.02
1843.2	1	3072	3072	1536	0	1536	2/3	1
1228.8	2	4096	3072	3136	1	64	1/3	1.02
2457.6	1	4096	3072	1536	0	1536	2/3	1

Table 2.15: Sequence Repetition and Symbol Puncturing Parameters

2.3 Sequence Repetition and Symbol Puncturing

The sequence repetition and symbol puncturing parameters are shown in Table 2.15. The column in Table 2.15, *No. of Modulation Symbols Need*, is equal to number of TDM chips in Table 2.2. If the number of modulation symbols is higher than the number obtained. Required as many full-sequence times complete transmission is occurred and the partial transmission is followed if necessary.

Data Rate (kbps)	Slots	Bits	Preamble Chips	Pilot Chips	MAC Chips	Data Chips
38.4	16	1024	1024	3072	4096	24576
76.8	8	1024	512	1536	2048	12288
153.6	4	1024	256	768	1024	6144
307.2	2	1024	128	384	512	3072
614.4	1	1024	64	192	256	1536
307.2	4	2048	128	768	1024	6272
614.4	2	2048	64	384	512	3136
1228.8	1	2048	64	192	256	1536
921.6	2	3072	64	384	512	3136
1843.2	1	3072	64	192	256	1536
1228.8	2	4096	64	384	512	3136
2457.6	1	4096	64	192	256	1536

Table 2.16: Preamble, Pilot, MAC, and Data Multiplexing Parameters

2.4 Time-Division Multiplexing

As shown in Figure 2.10-2.13, the Forward Traffic Channel or Control Channel data can be time-division multiplexed with preamble, Pilot Channel, MAC Channel chips. The multiplexing parameters can be found in Table 2.16. The Walsh chip rate is constant at 1.2288 Mcps.

2.5 Quadrature Spreading

As depicted in Figure 2.3, quadrature spreading employs the combined modulation sequence. The spreading sequence can be a quadrature sequence of length 32768 PN chips [45]. This sequence can be used following polynomials: For in-phase sequence

$$P_I(x) = x^{15} + x^{10} + x^8 + x^7 + x^6 + x^2 + 1 \quad (2.5)$$

For quadrature sequence

$$P_Q(x) = x^{15} + x^{12} + x^{11} + x^{10} + x^9 + x^5 + x^4 + x^3 + 1 \quad (2.6)$$

The maximum length of the linear feedback shift register is 2^{15}-1 and can be produced following equations:

$$I(n) = I(n-15) \oplus I(n-13) \oplus I(n-9) \oplus I(n-8) \oplus I(n-7) \oplus I(n-5) \quad (2.7)$$

and

$$Q(n) = Q(n-15) \oplus Q(n-12) \oplus Q(n-11) \oplus Q(n-10) \oplus Q(n-6) \oplus Q(n-5) \oplus Q(n-4) \oplus Q(n-3) \quad (2.8)$$

2.6 Filtering

Baseband Filtering

After the quadrature spreading operation, the I‘ and Q‘ are employed to the baseband filter as depicted in Figure 2.3. The Figure 2.17 shows the frequency response S(f) limits. The numerical values of the parameters are δ_1= 1.5 dB, δ_2= 40 dB, and f_p= 740 kHz. The proper baseband filter impulse response, s(t), the following equation should satisfy

$$Mean\ Squared\ Error = \sum_{k=0}^{\infty}[\alpha s(kT_s - \tau]^2 \leq 0.03 \quad (2.9)$$

where the constant α and τ help to minimize the mean square error. The parameter, T_s, is 203.451 ns. The Table 2.17 shows the baseband filter coefficients.

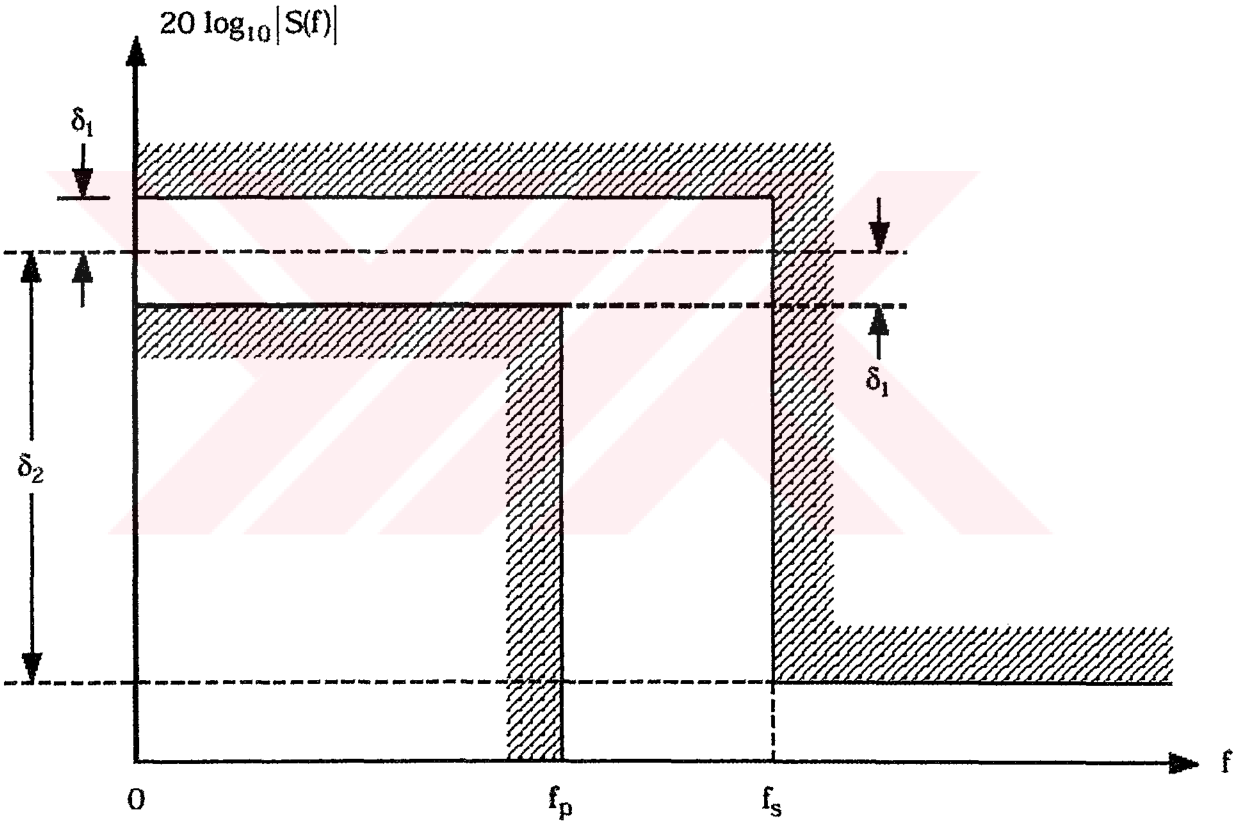

Figure 2.17: Baseband Filter Frequency Response Limits

Phase Characteristics

The phase equalization achieved via the equalizing filter which has a following transfer function

$$H(w) = K \; \frac{w^2 + j\alpha w w_0 - w_0^2}{w^2 - j\alpha w w_0 - w_0^2} \tag{2.10}$$

where K is the gain, j is equal to $\sqrt{-1}$, α is equal to 2π x 3.15 x 10^5, and w is the radian frequency [45].

2.7 Conclusions

In IS-856, the MS, using the time-multiplexed pilot channels to produce estimates of the SNR levels from each BS, selects the best possible server. Based on the SNR level from the serving BS, the MS can then determine the highest data rate that it can support at the required packet error rate. The data rate used to transmit the information packet is determined by channel conditions. When conditions are unfavorable, a lower data rate with more slots is used. As stated earlier, each BS transmits to only one MS at any given time in IS-856. If there are more than one MS requesting service at any given time, the BS must select which mobile to transmit to using a scheduling algorithm. To aid the BS with this process, each MS sends a message indicating the maximum data rate it can support on the downlink every 1.667 ms.

In this chapter, the IS 856 airlink, and the IS-856 Forward Link structure such as IS-856 Forward Link Channels, Forward Link encoding, scrambling, modulation, and channel interleaving specifications are described in detail. In addition to them, processes, sequence repetition and symbol puncturing, time-division multiplexing, quadrature spreading, and filtering, are explained for understanding overall IS-856 Forward Link to increase system throughput via scheduling algorithm that is explained in Chapter 3.

k	h(k)
0,47	-0.025288315
1,46	-0.034167931
2,45	-0.035752323
3,44	-0.016733702
4,43	0.021602514
5,42	0.064938487
6,41	0.091002137
7,40	0.081894974
8,39	0.037071157
9,38	-0.021998074
10,37	-0.060716277
11,36	-0.051178658
12,35	0.007874526
13,34	0.084368728
14,33	0.126869306
15,32	0.094528345
16,31	-0.012839661
17,30	-0.143477028
18,29	-0.211829088
19,28	-0.140513128
20,27	0.094601918
21,26	0.441387140
22,25	0.785875640
23,24	1.0

Table 2.17: Baseband Filter Coefficients

Chapter 3

SCHEDULING ALGORITHMS FOR IS-856 & MULTIMEDIA APPLICATIONS

Perhaps the most crucial component of the opportunistic multiple access communication system under study is the employed scheduling algorithm. The scheduler allocates the system resources to different users in a time-multiplexed fashion. The choice of the scheduling algorithm affects the system throughput as well as the average delay experienced by users in between successive accesses to the system. Henceforth, this chapter will analyze present scheduling algorithm, proportional fair, and other well-known algorithms, then, propose five new scheduling algorithms to compare with others. Furthermore, adding appropriate terms into the scheduling algorithms will support multi service and multicast applications.

As stated in the previous chapter, the optimal scheduling rule is one where the user with the best channel conditions is scheduled for service. However, we have also stated that such an algorithm would result in user starvation [14]. Moreover, this scheme is only concerned with optimizing the system throughput and not with satisfying the quality-of-service (QoS) requirements of the services offered. Notwithstanding, for certain multimedia applications, it is known that the latency requirements are just as important as the throughput. Nevertheless, this rule provides the maximum system throughput at the expense of keeping some of the users waiting for service for extended periods of time, if not forever. Thus services that require latency guarantees can not be properly be offered using such a scheduling rule. Furthermore, in a system where resource allocation is done merely based on the observed channel conditions; users near cell boundaries are likely to receive system access much less frequently than that closer to the cell center. The scheduling algorithm has to find a way to make sure that users, regardless of their geographical location, are treated somewhat fairly. In other words, one has to ensure that even the most disadvantaged user has a chance of accessing the system without an exhaustive latency.

Thus, it is clear that a practical, proper scheduling algorithm should take the individual forward channel characteristics of the MSs as well as the individual quality-of-service (QoS) requirements of the individual users into account that realizes a reasonable trade off between efficiency and fairness, consists in transmitting to the user with the highest potential rate proportionally to user current mean data rate [14, 15]. The ultimate goal is to find a rule where the users don't experience large latencies and the variations in the latency values of the users are not too large all the while making sure that the optimal system throughput value is not compromised too much. Unfortunately, there exists a dichotomy between increasing the system throughput and decreasing the observed user latency when one uses the opportunistic multiple access scheme.

3.1 Scheduling Algorithms for IS-856

Numerous scheduling algorithms have appeared in the literature. In [16],[17],[18],[19],[28], scheduling algorithms effort to exploit the "multi-user diversity" in a fading surrounding. The algorithms in [16],[17],[18], give a service to users with favorable channel conditions where the channel is modelled as a simple two-state process with a "good" and "bad" channel state but this contribution is not sufficient in real situations. Improved scheduling algorithms, that utilize combined knowledge of the queue length, latency, waiting time and channel conditions are explained in [20],[21],[22],[23],[28]. Fairness is a crucial subject for scheduling such as delay and worst-case guarantees on throughput to fulfill some degree of separation between flows. The generalized processor sharing (GPS) model explained in [24] and [25] is used in [19]. In [26] applied a utility-based approach in wireless channel conditions.

The scheduling algorithms under consideration in this thesis are the Maximum C/I rule and the FIFO rule as the two benchmarks, the proportionally fair (PF) algorithm proposed by Qualcomm [27], the exponential rule [28], the modified Longest Weighted Delay First (M-LWDF)[29], hybrid of the maxD and PF algorithms maxD/PF-0.25

and maxD/PF-0.75 [31], and the five new schemes that are developed based on the lessons learned from the performance analysis of the PF rule, the modified Longest Weighted Delay First, and the exponential rule. To describe these algorithms, let us first define the following:

- t_s: the length of the time slot for which the resource allocation state is maintained in the system.
- $r_i(kt_s)$: the data rate supported by the forward link channel of user i at the k'th time slot.
- $\overline{r_i(kt_s)}$: the average data rate observed by user i defined over a long, predefined, sliding window of length T slots spanning the time $[(k-1-T)t_s, (k-1)t_s]$.
- $l_i(kt_s)$ is the number of slots user i has spent without service.

3.1.1 Maximum C/I Scheduler

As stated before, this is the system throughput optimal scheduler under idealized conditions. Using this rule, at a given time, the user experiencing the best C/I level is scheduled for service. When adaptive coding and modulation are used, it is possible to interchangeably use the channel C/I levels and the corresponding observable data rates from users as inputs to the scheduling algorithm. Mathematically then, we schedule user,

$$j = \arg\max_i r_i(kt_s). \tag{3.1}$$

at time slot k. For reasons described above, the maximum C/I scheduler is likely to cause unfairness across users and at worst, user starvation and thus is not suitable for practical use. However, the system throughput optimality makes this rule a good benchmark to realize how much one deviates from the optimal throughput result using the practical algorithms considered in this thesis.

3.1.2 FIFO Scheduler

The FIFO scheduler sits at the other extreme of the spectrum from the maximum C/I scheduler in that, it simply schedules the user who has waited for the longest time for service. Mathematically, scheduler schedules at time slot k, the user,

$$j = \arg\max_i \, l_i(kt_s). \tag{3.2}$$

Clearly, unlike the maximum C/I scheduler, this policy is oblivious to the wireless channel characteristics and therefore does not utilize the multi-user diversity at all. Use of the opportunistic multiple access scheme becomes meaningless if one were to use the FIFO scheduler, as no additional gains would be achieved from it. While the FIFO scheduler performs very poorly from a system throughput perspective, it is obvious that it will achieve the best latency performance of all schedulers under study. Once again, for this reason, it can be used as a good benchmark to see how the relative latency performances of the practical algorithms rank up relative to the optimal performance.

3.1.3 Proportionally Fair (PF) Scheduler

The proportional fair scheduler algorithm was developed in 1999 for use with the IS-856 system [52]. According to the information theoretic results of Knopp and Humblet [6] and that of Tse [54], IS-856 adopted a MAC layer packet scheduling algorithm [33], [27] based on a proportionally fair (data) rate-per-unit-charge criterion [34] for applications with elastic traffic. By elastic traffic we mean the applications are able to modify data transfer rates [53]. The PF rule recognizes that the multi-user diversity can be exploited only by taking advantage of the temporal variations of the channel by scheduling transmissions to mobiles during time periods where the mobiles see strong levels, but also attempts to solve the issue of fairness among the users. With the PF rule, users compete for resources not directly based on their observed channel conditions but only on how strong their observed channel conditions are relative to their own average channel observations. Namely, the scheduler pushes the total long-term average user throughput towards the total capacity of the system by allotting the system resource to a single user with the best channel condition at every time slot [53]. Clearly there is a direct link between the observed channel conditions and the achievable data rates when adaptive coding and modulation are used. Therefore, instead of the channel C/I levels, as with the C/I rule, here the scheduler may use the achievable data rate values from the users as well. Then, mathematically at time t, the PF scheduler schedules user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \right). \tag{3.3}$$

where the average data rate for user i, $\overline{r_i(kt_s)}$ is calculated using a sliding window of length T slots as follows,

$$\overline{r_i((k+1)t_s)} = \begin{cases} \left(1 - \frac{1}{T}\right) r_i(kt_s) + \frac{1}{T}\overline{r_i(kt_s)} & \text{if user } i \text{ is scheduled} \\ \left(1 - \frac{1}{T}\right) r_i(kt_s) & \text{if user } i \text{ is not scheduled} \end{cases} \tag{3.4}$$

The PF rule aims for fairness through the observation that the user with a geographically closer location to the base station will most likely have a higher average throughput than a user at the cell boundary. Since the PF rule only ranks the users according to their instantaneous channel qualities relative to their own average channel conditions, the users that have higher average throughput are not necessarily at an advantage.

It is obvious that the parameter T is an important parameter to the PF scheduler performance. If T is set to be large, the impact of the last time slot will be small on the average data rate. Thus, in a user with many users, the user whose channel hits a really high peak will be scheduled for service. This means that, overall, the users will be allowed to observe larger latencies.

One important concern with the PF rule rises when users with different Doppler frequencies fight for resources. This is because users with high Doppler frequencies will experience fast fading where the states of their channels can switch from good to bad within a short time span and vice versa. On the other hand, users with low Doppler frequencies will not observe large variations from their average channel conditions, which is largely dictated by the user location and interference level. Thus, provided that the channel information from all users is accurate and timely, it is clear that a high Doppler frequency user will more likely observe a relative high peak of its channel resulting in the PF rule unfairly favoring it over the smaller Doppler frequency users [35].

3.1.4 Exponential Scheduler

The exponential rule, developed by Shakkottai and Stolyar in 2000 [28] is a PF rule that also tries explicitly to equalize the latencies of all the users when their differences become large. At time slot k, the user,

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \exp\left(\frac{l_i(kt_s) - \overline{l(kt_s)}}{1 + \sqrt{\overline{l(kt_s)}}} \right) \right) \tag{3.5}$$

is scheduled. Here,

$$\overline{l(kt_s)} = \frac{1}{N} \sum_{i=1}^{N} l_i(kt_s) \tag{3.6}$$

is the average of the latencies observed by all of the N users in the system at time slot k.

In (3.5), a large latency observed by one of the users relative to the overall average latency results in a very large exponent, overriding the channel conditions and leading to the large latency user getting priority. On the other hand, for small weighted latency differences, the exponential term is close to 1 and the policy becomes virtually the PF rule. In (3.5 the term in the denominator of the exponential term may be dropped with no change in performance since it is the same for all users. However, its presence gives an intuitive understanding that the exponent term will override the scheduling parameter for one of the users if the relative latency offset for this users is greater than that of the others by an order of $\sqrt{\overline{l(kt_s)}}$. The exponential rule adapts itself from a PF rule to one that balances the user latencies depending on the channel condition and latency information it receives from all of the users.

Shakkottai and Stolyar prove that the exponential rule is throughput-optimal. By throughput-optimality, they mean that the rule ensures the stability of the user specific queues at the base station. In other words, one user's queue will grow out of bounds under normal traffic conditions if one were to use the exponential rule. However, the same property cannot be claimed for the PF rule. Since the PF rule tends to favor high Doppler frequency users over low Doppler frequency users, a static or near static user may, for a certain practical scenario, may starve for service for an extended period of time, during which its queue at the base station may grow out of bounds.

3.1.5 Modified Largest Weighted Delay First (M-LWDF)

The Modified Largest Weighted Delay First (M-LWDF) rule, formulated by M. Andrews et al., has been showed analytically that the M-LWDF scheduling algorithm is throughput optimal [29, 30]. The major contribution of this algorithm is that a scheduler utilizes on both current wireless channel conditions and the weighted latencies of individual users. Furthermore, the M-LWDF algorithm is very easy to carry out. At time slot k, the user,

$$j = \arg\max_i \frac{r_i(kt_s)}{\overline{r_i(kt_s)}} l_i(kt_s) \tag{3.7}$$

is scheduled.

3.1.6 maxD/PF-0.25 & 0.75

The maxD/PF rule, formulated by Elliott and Krzymien in 2002 [31] is a mixture of the maxD which is a different version of Maximum C/I, and PF algorithms with an adjustable parameter to control the throughput and latency features. At time slot k, the user,

$$j = \arg\max_i \left(a\frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \right) + (1-a) \left(\frac{r_i(kt_s)}{\overline{r_i(kt_{sAV})}} \right) \tag{3.8}$$

is scheduled. The parameter "a" is to manipulate the throughput and latency features between those of the maxD and PF schedulers. The range of "a" is changes from 0 to 1, when "a" is equal to 0, the maxD/PF algorithm equals to maxD algorithm; likewise, when "a" is equal to 1, the algorithm matches to the PF algorithm. In the simulations, "a" was taken 0.25 & 0.75.The parameter $r_i(kt_{sAV})$ is the average value of $r_i(kt_s)$ over all users in the cell.

3.1.7 New Scheduler # 1

Based on the findings of the PF and Exponential Rule, it is clear that a proper scheduling algorithm needs input from the time-varying channel characteristics of the users to exploit multi-user diversity and from the experienced user latencies to provide for fairness as well as proper multi-service QoS provisioning. Mathematically then, the ideal scheduler will schedule user

$$j = \arg\max_i \left(f\left(r_i(kt_s), \overline{r_i(kt_s)}\right) \; g\left(l_i(kt_s), \overline{l(kt_s)}\right) \right) \tag{3.9}$$

where $f(\cdot)$ and $g(\cdot)$ are two functions that need to be optimized. The PF rule lacks the second term of (3.9) with the hope that the first term will indirectly solve the problem of fairness. However, the practical systems of users with different services as well as different Doppler frequencies show that the presence of the second term is beneficial. Having stated this, should we assume that the exponential rule is the best possible scheduling algorithm for IS-856? Are there better possibilities? To answer these questions, we have conducted studies that resulted in five possible scheduling rules in the general form of (3.9).

The first of these rules is one where the linear multi-user diversity inducing term of the exponential rule is replaced by the square function. Intuitively, relative to the exponential rule, this scheme will give more weight to the achievable data rates and thus provide for a better system throughput. However, this will also have the negative impact of increasing the average experienced latencies. Details of the simulation results are given in the Chapter 4.

Mathematically, this scheduler schedules user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}}\right)^2 \exp\left(\frac{l_i(kt_s) - \overline{l(kt_s)}}{1 + \sqrt{\overline{l(kt_s)}}}\right) \tag{3.10}$$

at time slot k. Here,

$$\overline{l(kt_s)} = \frac{1}{N}\sum_{i=1}^{N} l_i(kt_s) \tag{3.11}$$

is the average of the latencies observed by all of the N users in the system at time slot k.

3.1.8 New Scheduler #2

The second proposed scheduler in this thesis increase the non-linearity order of both of the terms. The achievable data rates term is a cube function now, whereas the latency term has a steeper nonlinearity than the exponential term. Mathematically this scheduler schedules the user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}}\right)^3 6^{\left(\frac{l_i(kt_s) - \overline{l(kt_s)}}{1+\sqrt{\overline{l(kt_s)}}}\right)} \tag{3.12}$$

at time slot k.Here,

$$\overline{l(kt_s)} = \frac{1}{N}\sum_{i=1}^{N} l_i(kt_s) \tag{3.13}$$

is the average of the latencies observed by all of the N users in the system at time slot k.

3.1.9 New Scheduler #3

The third scheduler advised in this thesis that increases the throughput of M-LWDF by adding non-linearity parameter. The achievable data rates term is a power of five now; on the other hand the latency term is constant. Mathematically this scheduler schedules the user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}}\right)^5 \ l_i(kt_s)(3.14)$$

at time slot k.

3.1.10 New Scheduler #4

The fourth scheduler nominated in this thesis expansions the throughput of New Scheduler #3 by inserting non-linearity term. The achievable data rate term is persevering on the spot, considering the latency term is a power of 0.99. Mathematically this scheduler schedules the user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}}\right)^5 \ l_i(kt_s)^{\ 0.99} \tag{3.15}$$

at time slot k.

3.1.11 New Scheduler #5

The fifth scheduler considered in this thesis expansions the throughput of New Scheduler #1 by augmenting non-linearity term of throughput. The achievable data rates term is a cube function, considering the latency term is same as New Scheduler #1. Mathematically this scheduler schedules the user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{\overline{r_i(kt_s)}}}\right)^3 \exp\left(\frac{l_i(kt_s) - \overline{l(kt_s)}}{1+\sqrt{\overline{l(kt_s)}}}\right) \tag{3.16}$$

at time slot k.

3.2 Multi-Service Scheduling Algorithms for IS-856

The second contribution of this chapter is to support Multi-Service by appending Quality of Service parameters into the IS-856 scheduling algorithms. The IS-856 system maintains single type of service, in other words, all Quality of Service parameters, a_i's, are equal. Since on-line applications are very sensitive to the latency rather than the system throughput, the new type of services are created by changing the service parameters to hold up delay non-tolerant services. Due to observations of the previous section, Proportionally Fair, Exponential Rule, and proposed algorithms New Scheduler # 1, and New Scheduler #2 will be used as a multi-service schedulers and simulation results are depicted in chapter 4.

3.2.1 Multi-Service Proportionally Fair (PF) Scheduler

It is possible to use the PF scheduler to provide a number of services simultaneously. Depending on the QoS levels of the different types of services, each user may be given a weight, a_i where, smaller weights are given to users requesting services that are more latency tolerant. In this case, the PF scheduler schedules user

$$j = \arg\max_i \left(a_i \frac{r_i(kt_s)}{\overline{\overline{r_i(kt_s)}}}\right). \tag{3.17}$$

at time frame k.

3.2.2 Multi-Service Exponential Scheduler

Similar to the PF rule, it is possible to use the exponential scheduler to provide multi-service provisioning by assigning different weights to users based on the QoS requirements of their subscribed services. Once again, if a_i's are the so-called service specific user weights in a multi service system, the exponential rule schedules the user

$$j = \arg\max_i \left(a_i \frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \exp\left(\frac{a_i l_i(kt_s) - \overline{a\ l(kt_s)}}{1 + \sqrt{\overline{a\ l(kt_s)}}} \right) \right) \tag{3.18}$$

where

$$\overline{al(kt_s)} = \frac{1}{N} \sum_{i=1}^{N} a_i l_i(kt_s) \tag{3.19}$$

is the average of the weighted latencies observed by all of the N users in the system at time slot k.

3.2.3 Multi-Service New Scheduler # 1 or Multi-Service Modified Exponential-1

Like PF and the Exponential Rule algorithms, New Scheduler # 1 or Modified Exponential-1 what we called this scheduler is to wield multi-service provisioning by allocating dissimilar values to user dependent QoS requirements. Once more, if a_i's are the multi-service specific user values in a multi service system. Mathematically, this scheduler schedules user

$$j = \arg\max_i \left(a_i \frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \right)^2 \exp\left(\frac{a_i\ l_i(kt_s) - \overline{a\ l(kt_s)}}{1 + \sqrt{\overline{a\ l(kt_s)}}} \right) \tag{3.20}$$

where

$$\overline{al(kt_s)} = \frac{1}{N} \sum_{i=1}^{N} a_i l_i(kt_s) \tag{3.21}$$

is the average of the weighted latencies observed by all of the N users in the system at time slot k.

3.2.4 Multi-Service New Scheduler #2 or Multi-Service Modified Exponential-2

Same as PF, Exponential Rule, and Modified Exponential-1, the Modified Exponential-2 can be used as a multi service supported scheduler. Theoretically this scheduler schedules the user

$$j = \arg\max_i \left(a_i \frac{r_i(kt_s)}{\overline{r_i(kt_s)}} \right)^3 6^{\left(\frac{a_i\ l_i(kt_s) - \overline{a\ l(kt_s)}}{1 + \sqrt{\overline{a\ l(kt_s)}}} \right)} \tag{3.22}$$

where

$$\overline{al(kt_s)} = \frac{1}{N}\sum_{i=1}^{N} a_i l_i(kt_s) \qquad (3.23)$$

is the average of the weighted latencies observed by all of the N users in the system at time slot k.

3.3 Multicast Scheduling Algorithms for IS-856

Finally, the third contribution of this chapter investigates an IS-856 system supporting a multicast service. Multicast represents an efficient mechanism that implements point-to-multipoint communications. Applications that use it fall into two classes, namely, soft real-time and fully reliable multicast applications. Whereas the first of these handles delay sensitive applications such as video conferencing, service discovery and distance learning, the other class includes applications that expect reliable data transmission such as software distribution and access to distributed databases [60]. No proper multicast operation is realizable today's wireless systems. The IS-856 system renders well to multicast operation.

In this assistance, a scenario is investigated where 10% of the user population of a cell are multicast subscribers. The multicast service content is assumed to be delay tolerant. The remaining 90% of the users are assumed to subscribe to the delay-tolerant unicast service. We propose the following mode of operation for the IS-856 system in this case. The schedulers select users without taking the multicast service into account. If, for any of the time slots, one of the members of the multicast group is scheduled, the base station has to ensure that all members of the group receive the information properly. It therefore transmits the message at the lowest data rate that the multicast group members can support at that time instant. Whenever an individual user is scheduled, the operation is unchanged from the previous experiments. In the calculation of the throughput and latency figures, the fact that all multicast group members are serviced whenever one of them is scheduled is taken into account. In other words, for those time slots, the sum throughput is the transmission rate times the number of users in the multicast group. This scheme clearly exploits the multi-user diversity less for low Doppler frequencies relative to the system where no multicast service support is present. This is because, for time slots where a multicast member is scheduled, the transmission data rate is selected not based on the scheduled user but rather on the worst performing user of the multicast group.

According to findings of previous sections, Proportionally Fair, Exponential Rule, New Scheduler #1 & #2 are selected for multicast supporting operations because of valuable performances. Simulation results will be shown in Chapter 4 that provides system throughput and average latency figures as a function of the number of users for the IS-856 system. In the simulations, users are travelled with pedestrian(=3 km/hr), and mobile(=30 km/hr and 100 km/hr).

In conclusion, the vital part of the opportunistic multiple access communication system is the utilized scheduling algorithm. In this chapter, the schedulers, which present in the literature and proposed algorithms, are explained particularly. Moreover, in section 3.2, by adding multi service constants into the scheduling algorithms to support different type of services is also formulated. In addition to them, no proper multicast operation is achieved today's wireless systems. The IS-856 system can be easily adopt to multicast operation as seen in section 3.3.

Chapter 4

SIMULATION PLATFORM & RESULTS

To assess the relative performances of the scheduling rules described previous chapter; detailed simulations of the IS-856 system for single-service, combined single-service, multi-service, and multicast provisioning have performed using the scheduling algorithms discussed in the former chapter and the simulation results are drawn at the end of the chapter. The simulations are composed of three stages:

1. System Layer Simulations
2. Physical Layer Simulations
3. Resource Allocation Simulations

We consider the 2-tier 19-cell environment of Figure 4.1. Here, the first tier has 6 and the second tier has 12 cells centered on the cell of interest. Each cell is considered to have a radius of 1 km in the layout. We assume that 4000 users are dropped uniformly over the 19-cell layout of Figure 4.1. The intention is to find a cumulative distribution function for the observed carrier to interference (C/I) ratio across the geography of the center cell. Once 4000 users are dropped into the lay-out, the C/I is estimated for each user individually taking into account path loss, shadow fading, Rayleigh fading and the number of multipaths present in the radio environment of interest. Interference level is determined assuming that all base stations always transmit at full power. In other words, no base station experiences an idle slot at any time.

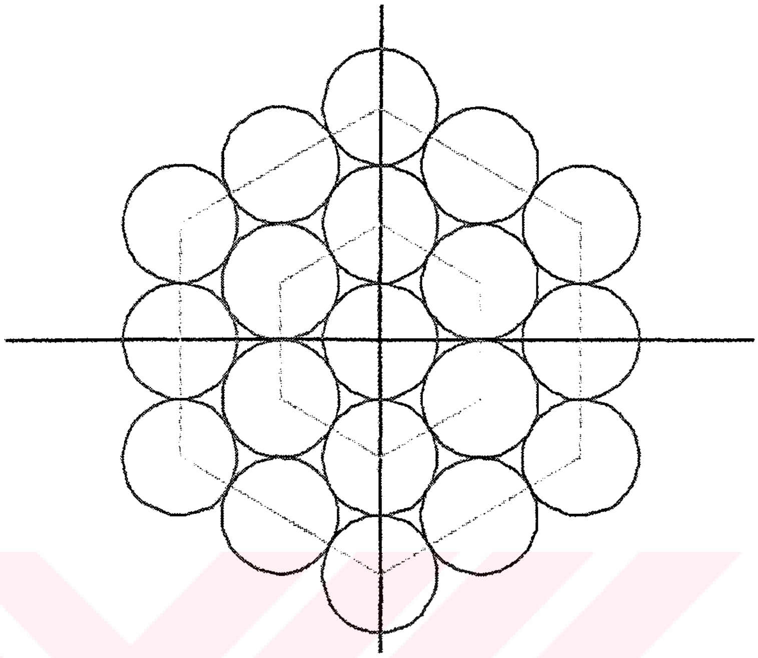

Figure 4.1: 2-Tier Cellular Layout

4.1 System Level Simulations

4.1.1 Path Loss Model

The COST231-Ikegami Walfish propagation model, which is appropriate for urban non-line-of-sight environments, is used in the simulations. This model is known to be accurate for the carrier frequency region of [800 MHz, 2GHz] and path distances in the range [20 m,5 km] [55].

Using this model, the path loss is written as,

$$L_P = \begin{cases} L_0 + L_{rts} + L_{msd} & \text{for } L_{rts} + L_{msd} \geq 0 \\ L_0 & \text{for } L_{rts} + L_{msd} < 0 \end{cases} \tag{4.1}$$

where L_0, L_{rts} and L_{msd} are the free-space loss, roof-to-street diffraction and scatter loss and multi-screen diffraction loss, respectively and are described as,

$$L_0 = 32.4 + 20\log_{10}(d) + 20\log_{10}(f_c) \tag{4.2}$$

$$L_{rts} = -16.9 - 10\log_{10}(w) + 10\log_{10}(f_c) + 20\log_{10}(\Delta h_m) + L_{ori} \tag{4.3}$$

$$L_{msd} = L_{bsh} + k_a + k_d \log_{10}(d) + k_f \log_{10}(f_c) - 9log_{10}(b) \quad (4.4)$$

In equations (4.2)-(4.3), d is the distance from a base station to a user, f_c is the carrier frequency and is set to be $f_c = 2$ GHz for this thesis. L_{ori} is the orientation loss defined as

$$L_{ori} = 4 - 0.114(\theta - 55) \quad (4.5)$$

with $\theta = 58.5$. $w = 25m$ is the width of the streets and Δh_m is the height of the mobile station antenna relative to the rooftops, $\Delta h_m = h_{roof} - h_m$. In the simulations, we let $h_{roof} = 15m$ and $h_m = 1.5m$, respectively. In equation (4.4) L_{bsh} is the shadowing loss when the base station antenna is above the rooftops and is defined as,

$$L_{bsh} = -18 \log_{10}(1 + \Delta h_b). \quad (4.6)$$

where Δh_b is the base station elevation with respect to the rooftops, $\Delta h_b = h_b - h_{roof}$ with the base station elevation set at $h_b = 50m$. Here, $k_a = 54$ and $k_d = 18$ are constant terms when the base station antenna is above the rooftops which is the assumed set-up in this thesis. The term k_f controls the dependency of the multi-screen diffraction loss on the frequency and is given by

$$k_f = -4 + 1.5(\frac{f_c}{925} - 1). \quad (4.7)$$

4.1.2 Forward Link Budget

The thesis assumed the following practical parameters for the forward link transmission in IS-856 is shown in Table 4.1 [56].

4.1.3 Shadow Fading, Rayleigh Fading and Multipath Models

Shadow fading is modelled as a log-normal random process with a standard deviation of 6.5 dB[56].

Following the ITU Vehicular B model [57], it is assumed that there are three resolvable paths at a bandwidth of 1.2288 Mhz. The Rayleigh fading multipaths are represented by Delay Spread Model. The fraction of power recovered (FRP) per tap is 50%,

Parameter	Value
Maximum Output power	42.3 dBm
Base Station Antenna Gain	17 dBi
Antenna Cable Loss	3 dB
Fraction of the Transmitted Power Allocated to Data Transfer	78.125%
Total Transmitted Power on the Data Channel	55 dBm
Penetration Loss	10 dB
Minimum Required Received Data Channel Power	-85 dBm
Maximum Allowable Over the Air Loss	130 dB

Table 4.1: IS-856 Forward Link Budget

22%, and 10% for the first ray, second ray, and the third ray, respectively. 18% of the transmitted power is considered as an unrecovered power and taken into account interference [58].

Based on the above propagation models, C/I ratio is calculated for each user taking into account path-loss, shadow fading, Rayleigh fading, and 3 multipaths present in the radio environment. As stated previously, the interfering base stations are assumed to transmit at full power at all times. The maximal ratio combining is employed at the receiver. The detailed calculation of C/I values are enlighten below.

$$(C/I) = (C/I)_1 + (C/I)_2 + (C/I)_3 \tag{4.8}$$

where $(C/I)_1$, $(C/I)_2$, and $(C/I)_3$ are the Carrier to Interference Ratio (C/I) of Path 1, 2, and 3, respectively and are formulated as,

$$(C/I)_1 = RSP_1 - (TIPPN + RSP_2 + RSP_3 + UIP) \tag{4.9}$$

$$(C/I)_2 = RSP_2 - (TIPPN + RSP_1 + RSP_3 + UIP) \tag{4.10}$$

$$(C/I)_3 = RSP_3 - (TIPPN + RSP_1 + RSP_2 + UIP) \tag{4.11}$$

where UIP[58]is the Unrecovered Interference Power, RSP_1, RSP_2, and RSP_3 are the Received Signal Power (RSP)[58] of Path 1, 2, and 3, respectively and TIPPN[58] is the total interference power plus noise from other cell are described as,

$$TIPPN = \sum(55 - L_{P,i}) + PN \tag{4.12}$$

where i shows cell number from 1 to 18 interference base station and PN is the thermal noise can be calculated in 4.17.

$$RSP_1 = SP_1 - L_P - SF - URF \tag{4.13}$$

$$RSP_2 = SP_2 - L_P - SF - URF \tag{4.14}$$

$$RSP_3 = SP_3 - L_P - SF - URF \tag{4.15}$$

$$UIP = USP - L_P - SF - URF \tag{4.16}$$

where SF is the Shadow Fading effect, URF[59] is the Uncorrelated Rayleigh Fading, and USP[58] is the unrecovered signal power.

$$PN = 2kTB \tag{4.17}$$

where k is Boltzman constant (1.3806610^{-23} J/K), T is temperature (300K), and B is bandwidth (1.2288MHz).

The C/I values should be normalized to compensate for the real life imperfections such as inter-chip interference, loss of channel orthogonality due to transmit power amplifier non-linearity, presence of non-ideal spreading waveforms, analog-to-digital conversion quantization noise, and adjacent channel interference. A valid normalization model is given as [56]

$$(C/I)_N = \frac{(C/I)}{1 + \frac{(C/I)}{\alpha}} \tag{4.18}$$

where $\alpha = 13dB$ is a constant that accounts for all of the afore mentioned imperfections.

Once the C/I values for all of the dropped mobiles are calculated, it is possible to form the cumulative distribution function (cdf) of the C/I in an urban area cell of 1 km radius. The corresponding C/I cdf is plotted in Figure 4.2.

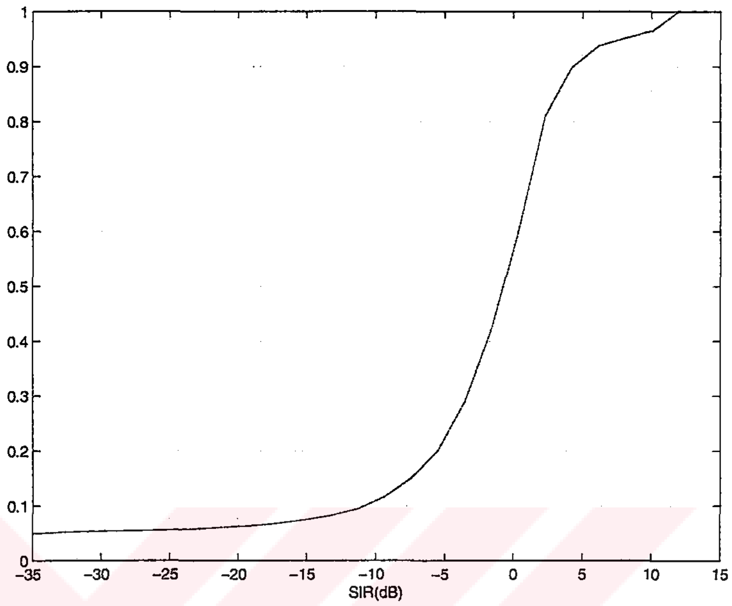

Figure 4.2: Cumulative Distribution Function of the C/I values for the 1 km urban cell

4.1.4 Mobility Model

The rate of change in the stochastic behavior of the wireless channel depends on the mobile speed as well as the carrier frequency. A good model for the autocorrelation of the channel characteristics of a mobile at a speed of v and carrier frequency f_c is given by Jakes as [1]

$$R_c(\tau) = J_0(2\pi f_d \tau) \tag{4.19}$$

The Doppler frequencies, f_d considered in this thesis are 0.9259 Hz, 5.56 Hz, 55.56 Hz and 185.185 Hz corresponding to mobile speeds of 0.5 km/hr, 3 km/hr, 30 km/hr and 100 km/hr, respectively.

The cdf for the C/I values achievable in the 1 km cell of interest was plotted in Figure 4.2. Here, mobility of users has not been taken into account. The mobility will be incorporated subsequently by means of a designed FIR filter built to provide the Jakes' spectrum. Parks-McClellan optimal equiripple FIR filters have been designed for the three mobile speeds considered in this thesis. The FIR filters have 513, 925, 925, and 925 taps, respectively, for the 100 km/hr, 30 km/hr, 3 km/hr and 0.5 km/hr cases that can be found Appendix A-D. Once the C/I values are generated based on the cdf of Figure 4.2, these numbers are passed through the corresponding FIR filters for proper mobility model.

4.2 Physical Layer Simulations

As seen in Table 2.2, data rates ranging from 38.4 kbps to 2.457 Mbps are supported in the IS-856 system using adaptive coding, modulation and varying physical layer packet sizes. Detailed physical layer simulations have been conducted to asses the performance of this system for all of the supported data rates taking into account all the blocks explained in Chapter 2 with using Agilent's ADS 2002C simulator. In all cases, both the data and the preamble performances have been investigated. A target physical layer packet error rate of 1% is assumed for all cases. The minimum required E_c/I_o and E_b/N_t levels have been found for an AWGN channel. The physical layer simulations have not taken the fading, multipath etc into account since these parameters are already included in the system level simulations as explained above. The underlying assumption here is that within a time slot of 1.67 ms, the C/I level for a mobile remains unchanged. The physical layer simulation results are depicted in Table 4.2.

For each of the data rates supported, the preamble, which is used to indicate the destination of a given physical layer packet, seems to have a significantly better performance than that of the data contents of the packet. This is to be expected, as the desired form of operation is one where all users are capable of correctly receiving the preambles of all packets.

4.3 Resource Allocation Simulations

Using the data from the system and physical layer simulations, we investigate the performance of the IS-856 system when the schedulers described in the previous chapter are employed. Different system scenarios are envisioned. First, a system with only a delay tolerant data system support is considered. Second, a system that supports

Data Rate	Packet Size	Number of Slots	Min Req E_c/I_o	Number of Chips	PG	Min Req E_b/N_t
38.4 kbps	1024	16	-11.77 dB	24576	24	2.03 dB
76.8 kbps	1024	8	-9.34 dB	12288	12	1.45 dB
153.6 kbps	1024	4	-6.3 dB	6144	6	1.58 dB
307.2 kbps	1024	2	-3.02 dB	3072	3	1.75 dB
614.4 kbps	1024	1	-0.8 dB	1536	1.5	0.96 dB
307.2 kbps	2048	4	-4.01 dB	6272	3.06	0.85 dB
614.4 kbps	2048	2	-1 dB	3136	1.53	0.85 dB
1.2288 Mbps	2048	1	3.52 dB	1536	0.75	2.27 dB
921.6 kbps	3072	2	1.48 dB	3136	1.02	1.57 dB
1.8432 Mbps	3072	1	7.6 dB	1536	0.5	4.59 dB
1.2288 Mbps	4096	2	3.52 dB	3136	0.77	2.36 dB
2.4576 Mbps	4096	1	10.54 dB	1536	0.33	6.28 dB

Table 4.2: Required E_c/I_o and E_b/N_t Values To Achieve A 1% Packet Error Rate For The IS-856 System In AN AWGN Channel

three different types of services with different QoS requirements is considered. Finally, a system that supports a delay tolerant data service as well as a multicast service is considered. In all cases, the goal is to investigate the performances of the schedulers in terms of the system throughput and user experienced average latency.

For each of the users present in the system, C/I levels for 20,000 successive time slots (33.4 seconds) are determined from the cdf distribution of Figure 4.2 which was developed through the system level simulations. Depending on the individual speeds of the mobiles, these streams of values are passed through the designed FIR filters to incorporate the corresponding Doppler effects. The physical layer simulations shown in Table 4.2 provide for the range of C/I values to ensure a 1% packet error rate transmission for all of the supported data rate classes. Therefore, it is possible to find out the highest data rate a user can sustain for each of the 20,000 time slots. It is assumed that information on these data rates is feedback by all mobiles to the serving base station at each time slot. This feedback is assumed to be error-free in our simulations and is assumed to arrive with a round-trip delay of 3 time slots. The serving base station is also assumed to keep a track of the up to date information on the latencies of the individual mobiles at all times.

With all of the information of the user supportable data rates and user latencies, the scheduling algorithms are invoked every time slot to decide on how to allocate the system resources. Based on the 20,000 time slots, the average system throughput as well as user experienced latencies can be found for each of the scheduling rules.

4.4 Simulation Platform Details

First, the system level simulations are performed. 4000 users are distributed uniformly over the 19-cell layout of Figure 4.1. The COST231-Ikegami Walfish propagation model of center cell is employed by using Equations 4.1-4.7 as explained in section 4.1.1. The pathloss of interference sources, which are the other base stations present in the layout, can be found by utilizing same equations. The IS-856 Forward Link Budged can be found in Table 4.1 that contributes to the total transmitted power and the transmitted power of each multipath. Total interference power plus noise that is the summation of the total transmitted power minus the pathloss of each interference base station plus thermal noise can be found with the aid of Equation 4.12. The Received Signal Power (RSP) of Path 1, 2, and 3 that contain fraction of total transmit power, pathloss, the Shadow Fading and the Uncorrelated Rayleigh Fading can be calculated as explained in Equations 4.13-4.16. Equations 4.9-4.11 assist the Carrier to Interference Ratio (C/I) of Path 1, 2, and 3. The Carrier to Interference Ratio (C/I) is calculated by Equation 4.8. Finally, the C/I values should be normalized to compensate for the real life imperfections and evaluated by Equation 4.18. After the system layer simulations, the cumulative distribution of C/I values plotted in Figure 4.2 is obtained.

Second, the physical layer simulations are employed by using Agilent's ADS 2002C simulator as clarified in section 4.2. This design includes transmitter and receiver of IS-856 Forward Link, AWGN and PER measurements that is used to calculate PER performance for forward traffic channel in AWGN channel with channel coding. The pilot, MAC, and traffic channels are time division multiplexed. Different data rates can be arranged via altering coding, modulation and packet size as narrated in chapter 2.

Third, for each data rate, probability distribution of C/I values is found with combining the cumulative distribution of C/I values as shown in Figure 4.2 and the physical layer simulation results as shown in Table 4.2. For example, 2.49% of the users transmit their data with 38.4 kbps and 2.35% of the users send their data with 2.4576 Mbps.

Fourth, resource allocation simulation is employed as explained in section 4.3. Simulation starts with loading channel filter constants that are evaluated by Jakes Model in section 4.1.4 and shown in Appendix A-D. Then, the simulation generates C/I values according to previously found probability distribution function with duration of 18000 time slots (30 sec.) plus the length of the channel filter constants (513 or 925 time slots). Later, mobility is added to the generated C/I values by convolving channel filter constants. Namely, generated C/I values are passed through the designed FIR filters to integrate the corresponding Doppler effect into the simulation as explained in section 4.1.4. After convolution, the first and last 513 or 925 time slots are discarded. So, 18000 C/I values are left.

Fifth, sliding window average is found for each scheduler, if scheduler needs sliding window average in the scheduling algorithm. Then, scheduler selects the user who will take service at that slot or 3 time slots after that depends on channel feedback information. After user selection, the scheduler algorithm can be updated. In other words, the scheduler increases latency values of the users who do not take a service at that time instant. After, the user who takes the service at that time slot, latency value sets to 0. Due to bad channel conditions, if selected user does not take a service at that instant, the latency value of the selected user can be increased. Then, sliding window average of the each user could be updated. Later, latency values of each user and throughput of selected user are aggregated. The scheduler iterates 18000 time slots. Consequently, the scheduler calculates average observed latency and throughput. The scheduler draws the simulation results that are "Observed Latency" and "System Throughput" versus "Number of Users" or "Window Size".

In the multicast simulations as explained in section 4.5.4, the scheduler can be updated more than one user at a time. That is to say, the scheduler may service a multicast group at that time instant. The latency values of the users, who take the service, are arranged to 0 in the current time slot by the scheduler. The throughput of the every serviced user is combined. Other steps are same as above paragraphs.

In the two users at a time scheduling algorithm simulations as narrated in chapter 5, the second, fourth and fifth steps are varied a little bit. The physical layer simulations of two users at a time scheduling are utilized with the aid of Agilent's ADS 2002C simulator as explained in chapter 5. Instead of one user, the Walsh codes are allocated for two users at specified time slot. So, newly proposed schedulers may service two users at this time slot, if the channel conditions are good. Then, the throughput of both of the users is summed and the latency values of the users are set to 0 at that time instant by the proposed scheduler. Other steps do not change.

In the Hot-Spot simulations as demonstrated in chapter 7, the scheduler may service with the higher data rate users if selected user present in the Hot-Spot. The first, fourth and fifth steps are changed. The differences of the system layer simulations can be written as follows. The thesis accepted that 2000 users are distributed uniformly over the 19-cell cellular environment and the 2000 users are dropped uniformly over the Hot Spot region. The positions of the Hot Spot and user distributions are shown in Figure 7.12-7.15. The Doppler frequency in the Hot Spot, f_d taken in this thesis is 0.925925 Hz that couples to mobile speed 0.5 km/h. The experienced (C/I) values are obtained in the Hot Spot as seen in Figure 7.16-7.19.

In the resource allocation part, the utility factor is added into the proposed algorithm to increase fairness as depicted in chapter 7. If the one of the Hot-Spot users is selected by the scheduler, the proposed algorithm controls the higher data rate users inside the Hot Spot, then, scheduler checks utility factor of the higher data rate users, which is the ratio between the number of times data received by mobile station and the number of times data sent. If all conditions are satisfied, the base station will transmit data to one of the higher data rate users with IS-856 network; then, this user sends data packets to the selected user via IEEE 802.11x network. The simulations presume that Wireless Local Area Networks (WLANs) are taken under nonpareil conditions. The other parameters do not alter in the simulations.

4.5 Simulation Results

Using the combined system level, physical layer and resource allocation simulations, single service scheduler results have been collected to investigate relative performances of proposed algorithms. Then, best of the two proposed algorithms are chosen to seek combined single service scheduler latency and throughput performances, finally, multi-service, and multicast scheduling performances will be analyzed which are the multimedia contributions of this thesis.

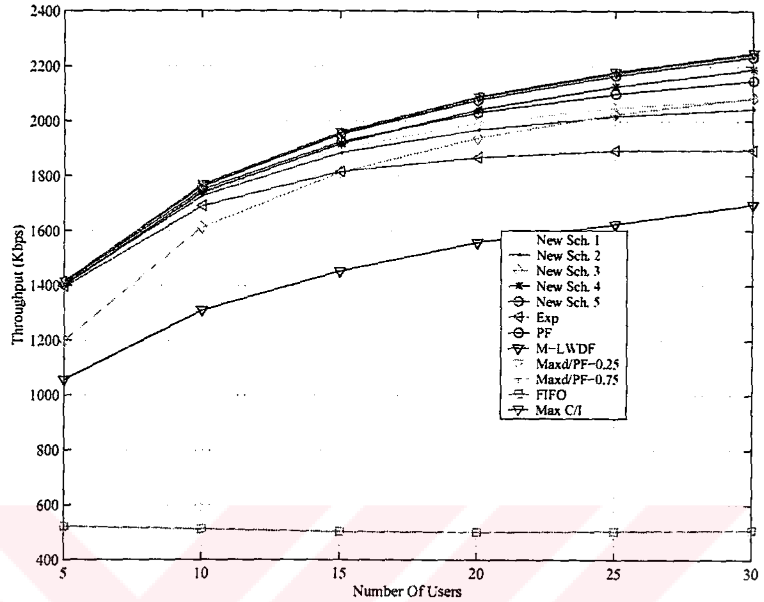

Figure 4.3: System Throughput versus Number of Users for the IS-856 System with perfect channel estimation for 3 km/hr users

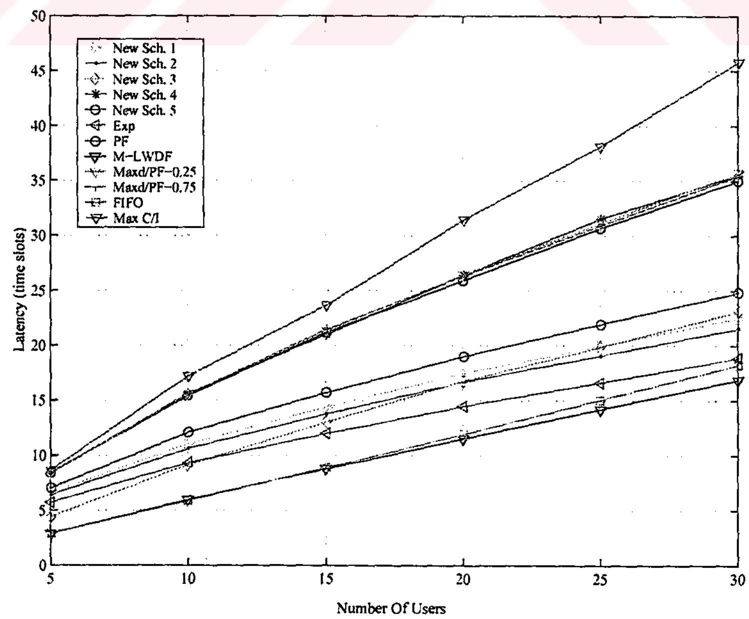

Figure 4.4: Observed Latency versus Number of Users for the IS-856 System with perfect channel estimation for 3 km/hr users

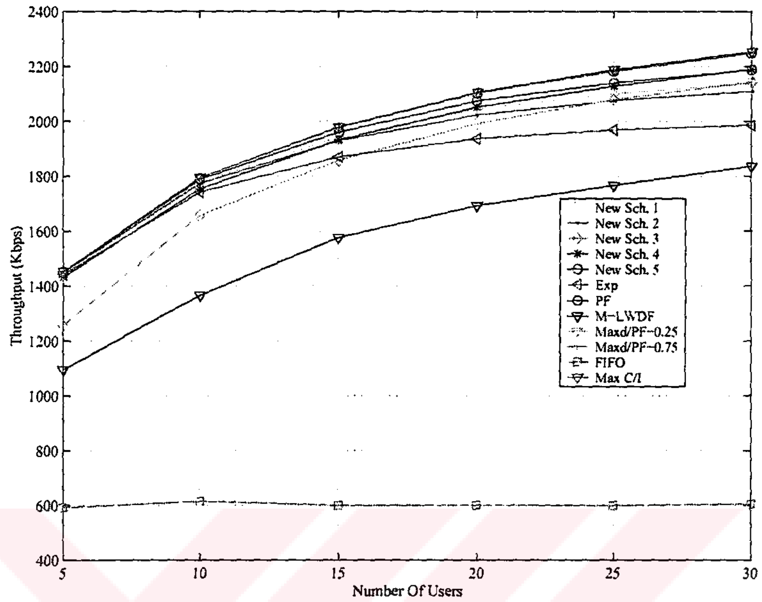

Figure 4.5: System Throughput versus Number of Users for the IS-856 System with perfect channel estimation for 30 km/hr users

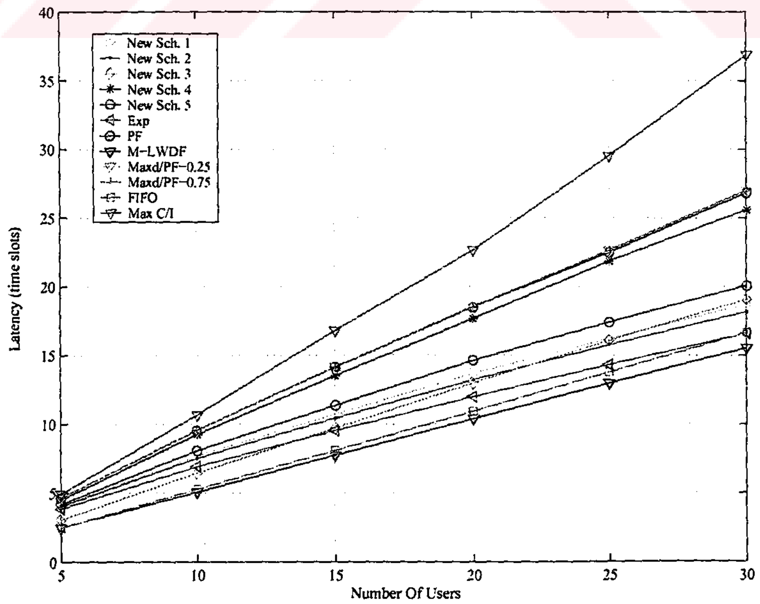

Figure 4.6: Observed Latency versus Number of Users for the IS-856 System with perfect channel estimation for 30 km/hr users

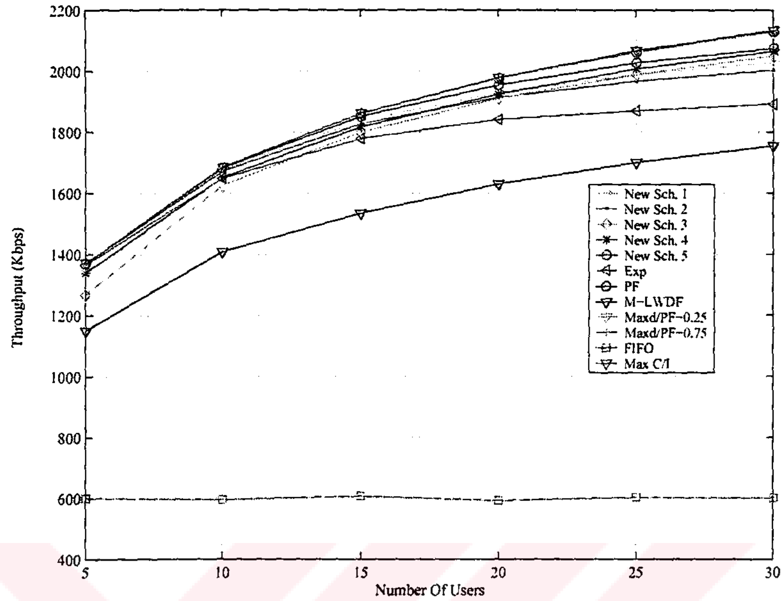

Figure 4.7: System Throughput versus Number of Users for the IS-856 System with perfect channel estimation for 100 km/hr users

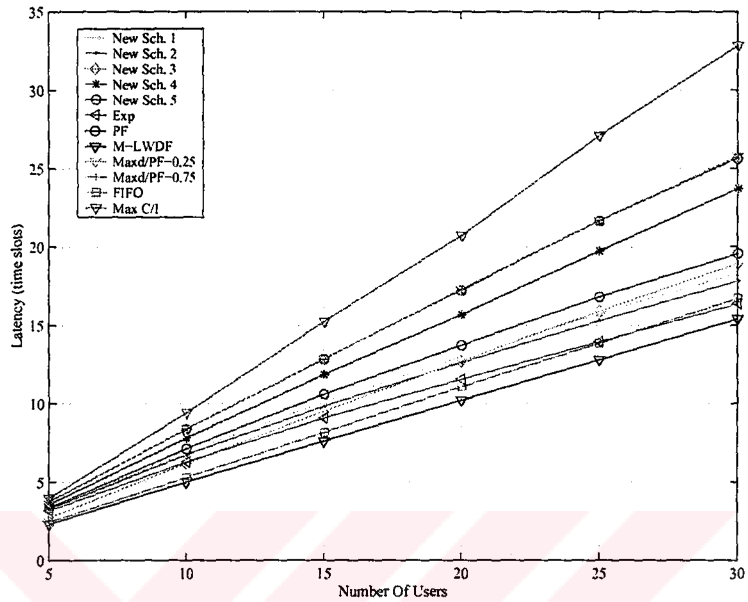

Figure 4.8: Observed Latency versus Number of Users for the IS-856 System with perfect channel estimation for 100 km/hr users

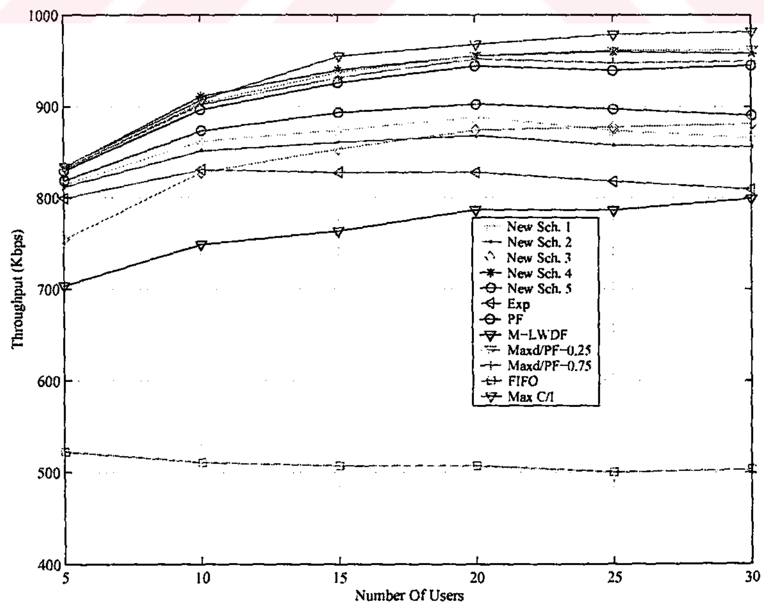

Figure 4.9: System Throughput versus Number of Users for the IS-856 System with 3 slot delay for 3 km/hr users

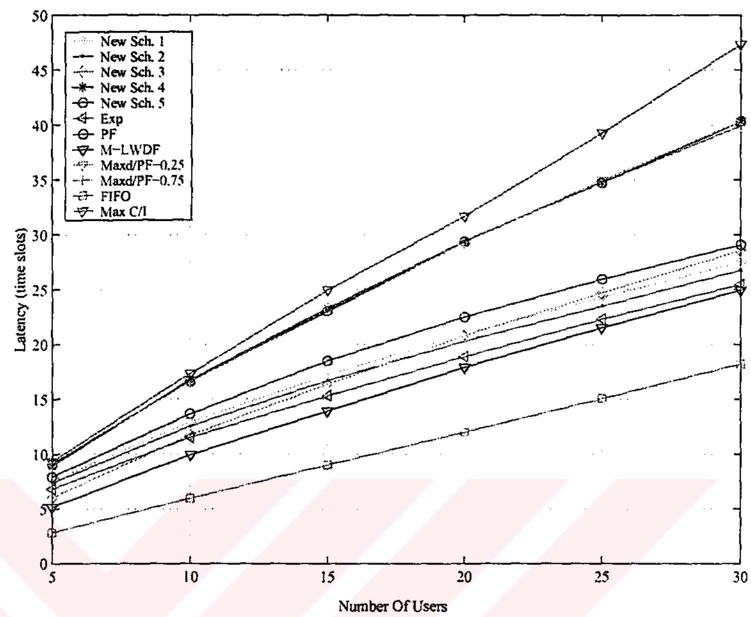

Figure 4.10: Observed Latency versus Number of Users for the IS-856 System with 3 slot delay for 3 km/hr users

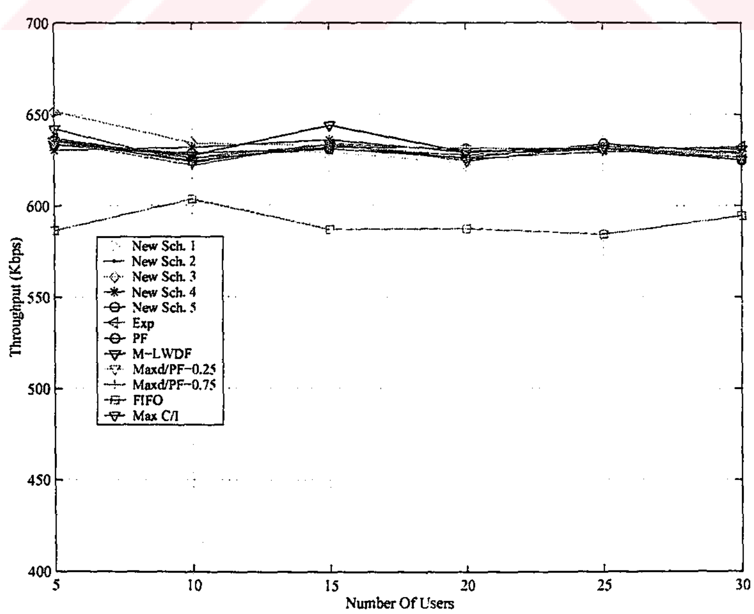

Figure 4.11: System Throughput versus Number of Users for the IS-856 System with 3 slot delay for 30 km/hr users

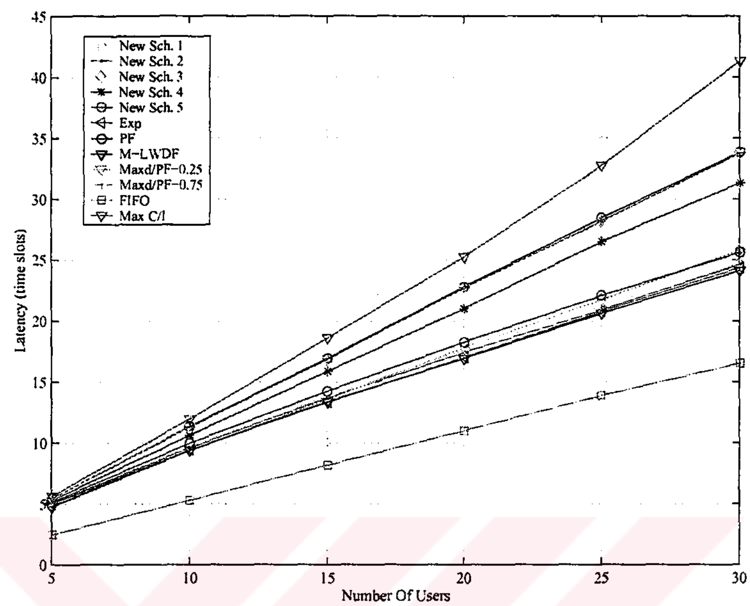

Figure 4.12: Observed Latency versus Number of Users for the IS-856 System with 3 slot delay for 30 km/hr users

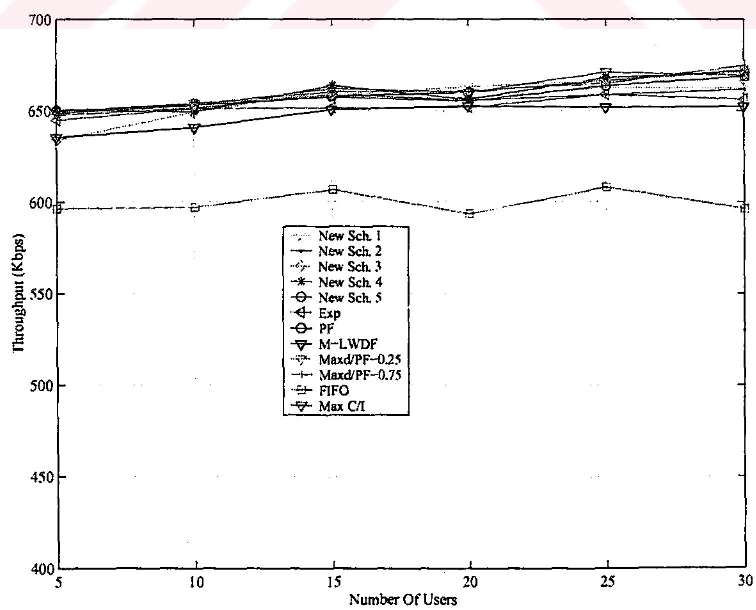

Figure 4.13: System Throughput versus Number of Users for the IS-856 System with 3 slot delay for 100 km/hr users

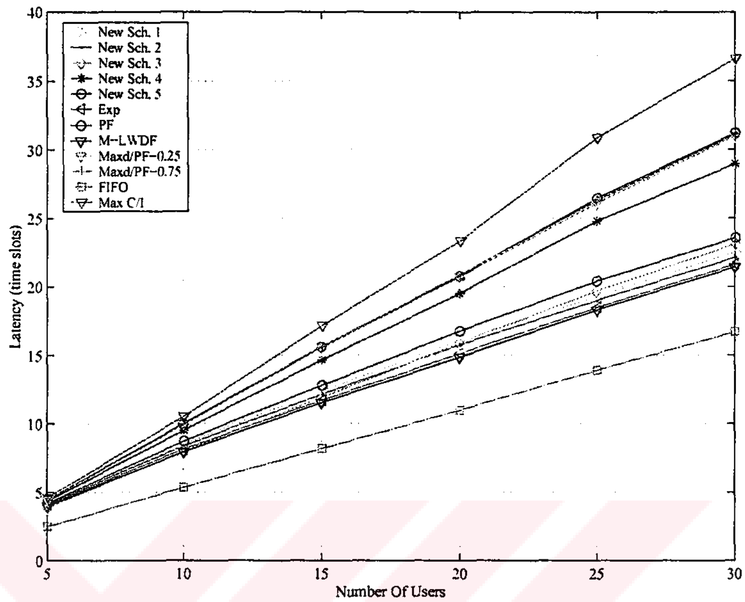

Figure 4.14: Observed Latency versus Number of Users for the IS-856 System with 3 slot delay for 100 km/hr users

4.5.1 Single Service Simulation Results

In the single server case, the IS-856 system is considered and investigated the change in the observed system throughput and average latency figures as a function of the number of users in the system. Results for the 3 km/hr, 30 km/hr and the 100 km/hr have been obtained. If the 3 slot round-trip feedback in the channel was non-existent, it is clear that the increase in the Doppler frequency would result in an increase in the system throughput. This is because, the higher Doppler frequencies result in larger deviations around the channel means, resulting in better utilization of the multi-user diversity inherent in the opportunistic multiple access scheme. However, the delayed feedback hurts the higher Doppler frequency users more than the others since the delayed feedback becomes more and more irrelevant as the Doppler frequency increases. In the end, we observe that the 100 km/hr and the 30-km/hr channels have lower system throughput than the 3-km/hr channel due to the delayed feedback.

Firstly, the perfect channel estimation performances of IS-856 with different schedulers will be analyzed. As stated before, when the Doppler frequency increases the throughput of the all schedulers has more throughput at 100-km/hr channel than the 3-km/hr channel. According to latency performance of the 3-km/hr channel, the schedulers are classified into four groups: first contains only Maximum C/I that has the worst latency and best throughput parameters. Proportional Fair, Maxd/PF-0.75, Maxd/PF-0.25, and New scheduler #4 is considered as a second group which have slightly less throughput performance but finer latency figures with respect to Max C/I. The third group is composed of New Scheduler #1, 2, 3, & 5 that are all newly proposed in this thesis and better latency values without too much hurt from the throughput more Figure 4.3-4.4. The last group incorporated Exponential Rule, FIFO, and M-LWDF that have lowest latency figures and the worst throughput performance all of the groups. In theory the FIFO Rule has lowest latency figures but due to outage probability the values a little bit worse than as an expected. The situation is not changed for the 100-km/hr channel and the 30-km/hr channel, just the throughput and observed latency performances are improved due fast changing of wireless channel as seen in Figure 4.3-4.8.

Due to unpredictable nature of the wireless channel, nobody can estimate channel perfectly,; namely, the three slot feedback delay is needed for practical applications. For this reason, the previous results depict theoretical performances of various schedulers. At that point, three-slot feedback delay added to simulations to get more realistic system performances and perfect channel estimation results will not be presented in the following chapters.

¿From Figures 4.9-4.14, it is clear that the scheme provides multi-user diversity with all scheduling schemes with the exception of the FIFO rule. This is natural as the FIFO rule does not use the channel state information in the decision making and thus has no ambition of ever utilizing the multi-user diversity. As expected the maximum C/I rule provides for the highest throughput value. The second group schedulers, PF rule, Maxd/PF-0.25 & 0.75, and New Scheduler #4 on the other hand, perform slightly better than the third and forth group schemes for the 3-km/hr channel. For the 100 km/hr and 30-km/hr channels, on the other hand, all schedulers seem to be performing on par with one another, experiencing only modest multi-user diversity gains.

As expected, the FIFO rule provides for the best latency figures for both cases and the maximum C/I provides for the worst values. As the number of user increase in the system, in all scheduling rules, the average observed latency increases. The rate of increase for the second group schedulers is greater than the rate of change for third and fourth group schedulers. When the cell population reaches 30 users, the second group schedulers results in latencies of 40 slots, around 33 slots and 30 slots for the 3 km/hr, 30 km/hr, and 100-km/hr channels, respectively. However, the third group schedulers on the other hand result in latencies of approximately 27 slots, 25 slots and 23 slots for the three speeds, only slightly larger than the fourth group schedulers rule. Thus, for all speeds, it is clear that the new scheduling rules in group 3,New Scheduler #1, 2, 3, & 5, provide for a significantly better latency performance with respect to the second group schedulers, with only a small reduction in the system throughput (on the order of 100 kbps) at low mobile speeds.

Selection of New Scheduler Algorithms

According to detailed simulations, current scheme PF is unfair if system contains different Doppler frequencies. On the contrary PF, Exponential Rule and M-LWDF are fair schedulers but their throughputs are low. To increase their throughputs, nonlinear terms are added into the scheduling algorithms. Then, to find appropriate numbers, many resource allocation simulations are performed. Finally, the terms are selected that provide for a very good overall performance in yielding good throughput values all the while maintaining latency figures close to those of the optimal values.

4.5.2 Combined Single Service Simulation Results

In previous part, thesis proposed 5 new scheduling algorithms. After detailed simulations, four of them give better performances with respect to latency and throughput. Since in real wireless environment all users do not move same speed, thus, the thesis selects two of the proposed schedulers, New Scheduler #1, & 2, to make elaborated simulations.

In this scenario, users composed of three groups: The first group consist of 10 pedestrian users with 3 km/hr speed, the second group includes 10 low speed mobile users with 30 km/hr, and the last group comprises 10 high speed motorway users with 100 km/hr. Again 3-slot delay is considered and the Max. C/I and FIFO Rule are taken as a benchmark algorithm which do not alter with employed window size, and PF, Exponential and New Scheduler #1, & 2 will be analyzed.

When analyzing the combined throughput and latency, as expected the Max.C/I rule behaves like a upper bound that has a maximum throughput and latency, and the FIFO rule acts rule as a lower bound which has a minimum throughput and latency. The combined throughputs of PF, Exponential, and New Scheduler #1, & 2 are approximately equal each other, but the combined latency of PF is 10 slots higher than the others as seen in Figures 4.15-4.16. To understand the source of very high latency, the throughput and latency of each user group and variance of combined latency and throughput will be examined.

¿From Figures 4.17-4.24, the Max.C/I rule gives the highest throughput to the 3 km/hr user group but the 30 km/hr and 100 km/hr user groups are supported with lowest one. This is stems from better channel characteristics of 3 km/hr users, namely, the other two groups take service rarely, that is the why, 30 km/hr and 100 km/hr users are exposed the maximum latency and variance values: 158 time slots for latency and 411 kbps for throughput. As stated before, the FIFO rule has a low latency and throughput values, however, the variance is the lowest for combined latency and throughput, in others words, every user is endangered same level of latency figures and takes same amount of data.

The PF scheme that is the first applicable scheduler from many telecom operators, has very strange characteristics. Due to fast variations of 30 km/hr and 100-km/hr channels, the probability of finding better channel conditions is increased, then, the user who belongs to these fast varying channels, the observed latency decreases if the window size increases, on the contrary, the subscriber travels with pedestrian speed(=3km), the observed latency is increases as the window size increases. To sum up these three groups, the overall observed latency decreases only certain point, after,

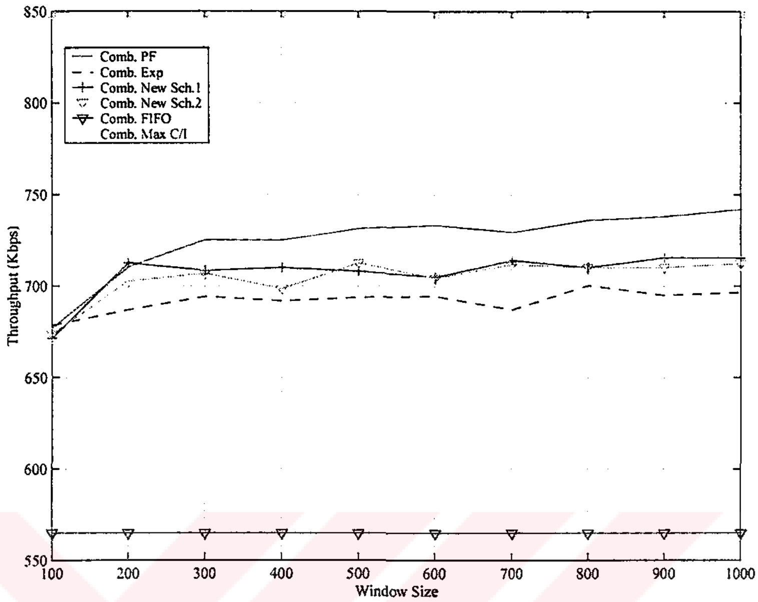

Figure 4.15: System Throughput versus Window Size for the IS-856 System with 3 slot delay for Combined System

it stays constant.

The Exponential rule with its derivatives, New Scheduler #1, & 2 exhibit better performances in combined system with regard to latency and throughput performances. The results confirm the intuition that the most famous scheme, PF rule, and Max.C/I are unfair in this scenario where users with different speeds access the system. Specially, higher mobility users will be favored by the PF rule, resulting in a significant increase in the observed latency for the low mobility users. The other schemes, on the other hand, observe comparable latencies for all users, regardless of their speeds. The proposed schemes, the new scheduler #1, & 2 observes a total system throughput very close to that of the PF rule and thus overall, have the better performance.

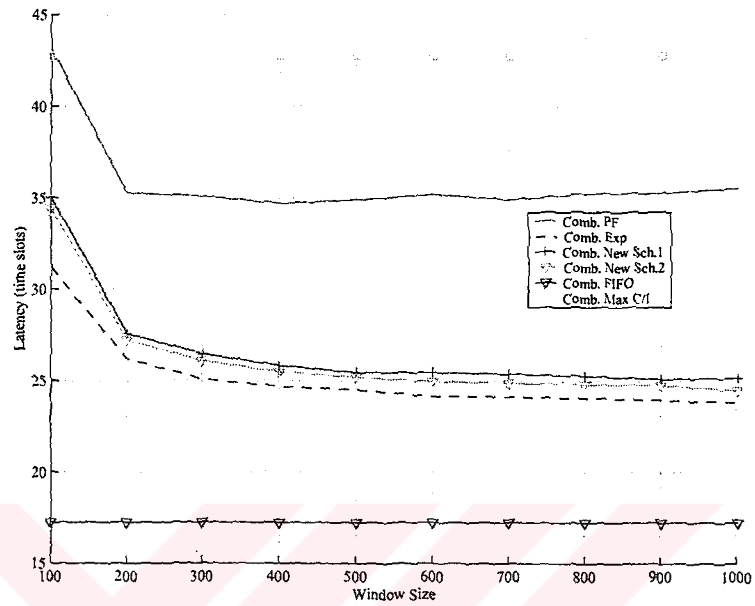

Figure 4.16: Observed Latency versus Window Size for the IS-856 System with 3 slot delay for Combined System

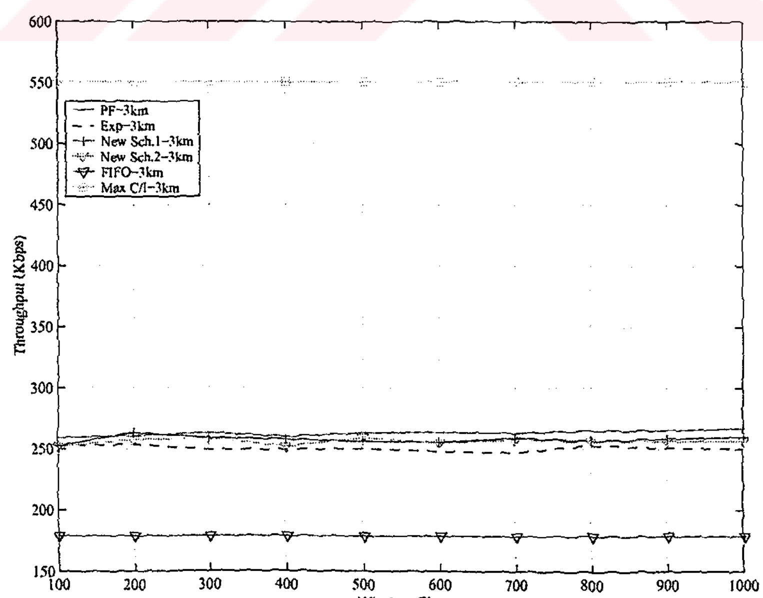

Figure 4.17: System Throughput versus Window Size for the IS-856 System with 3 slot delay for 3 km/hr users

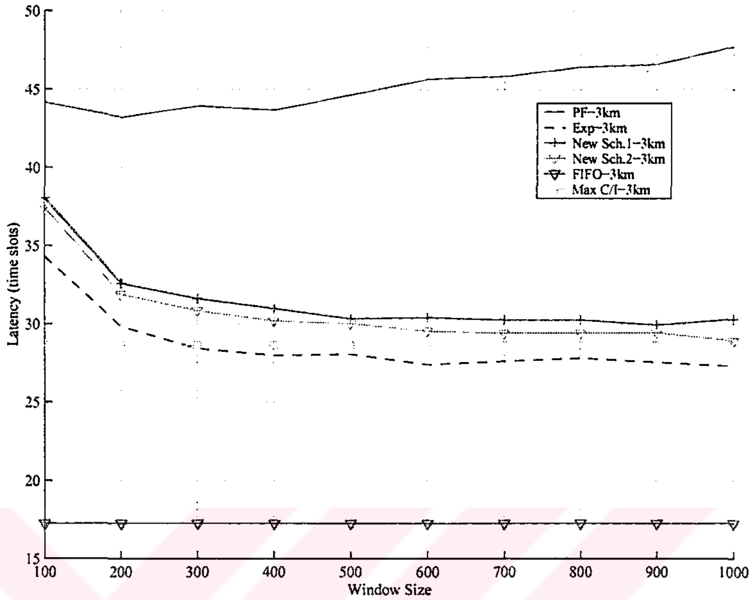

Figure 4.18: Observed Latency versus Window Size for the IS-856 System with 3 slot delay for 3 km/hr users

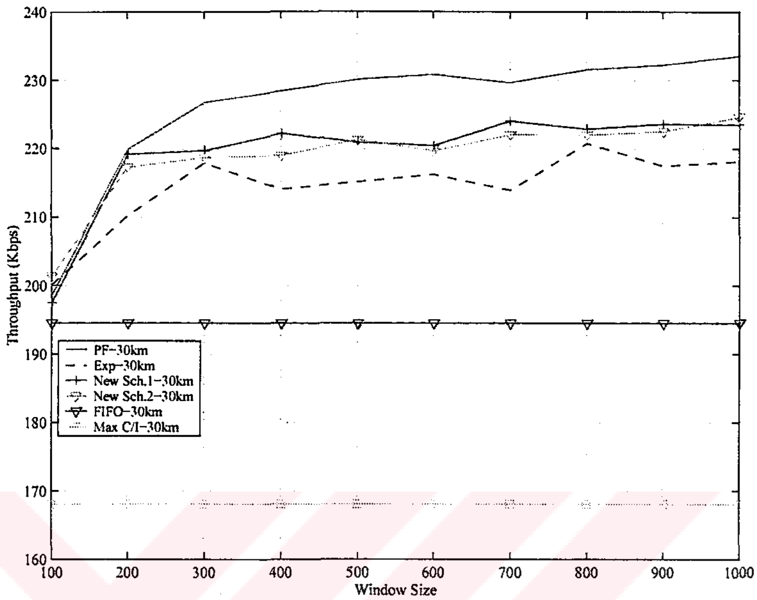

Figure 4.19: System Throughput versus Window Size for the IS-856 System with 3 slot delay for 30 km/hr users

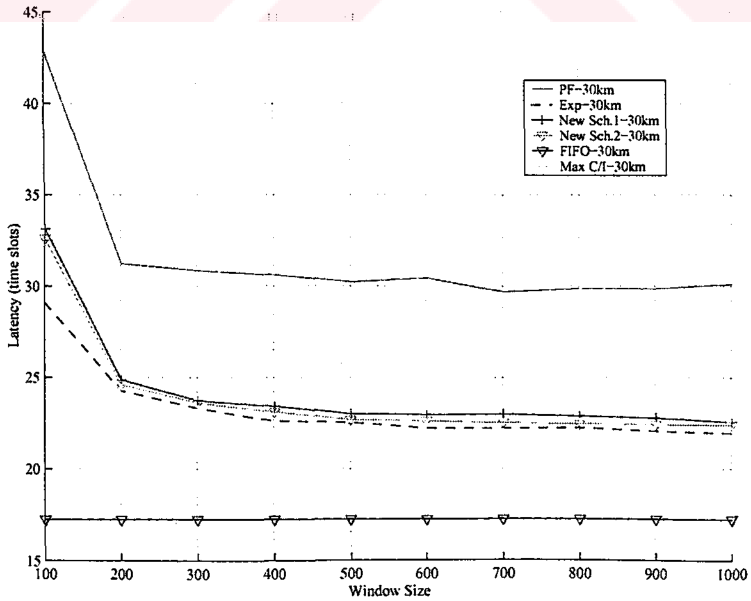

Figure 4.20: Observed Latency versus Window Size for the IS-856 System with 3 slot delay for 30 km/hr users

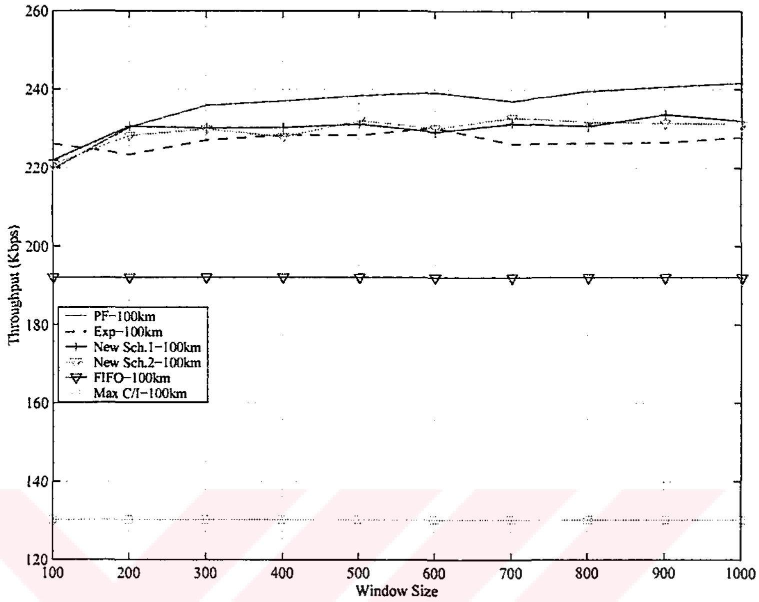

Figure 4.21: System Throughput versus Window Size for the IS-856 System with 3 slot delay for 100 km/hr users

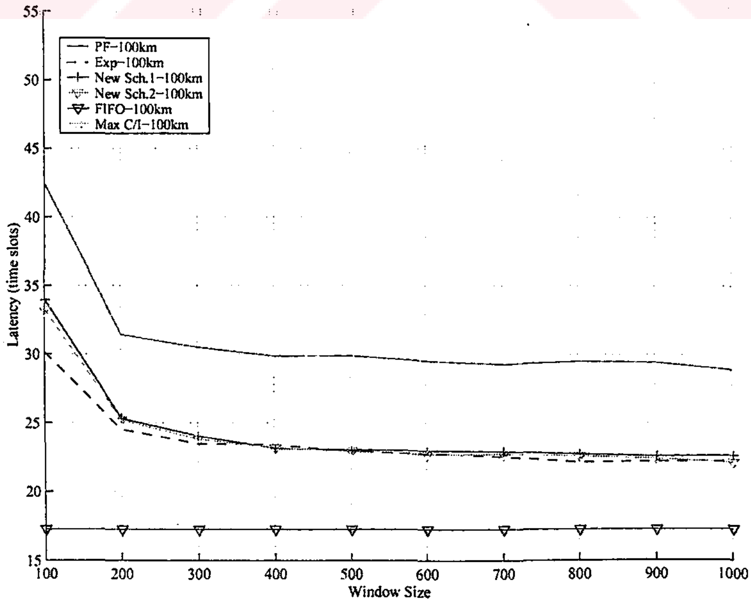

Figure 4.22: Observed Latency versus Window Size for the IS-856 System with 3 slot delay for 100 km/hr users

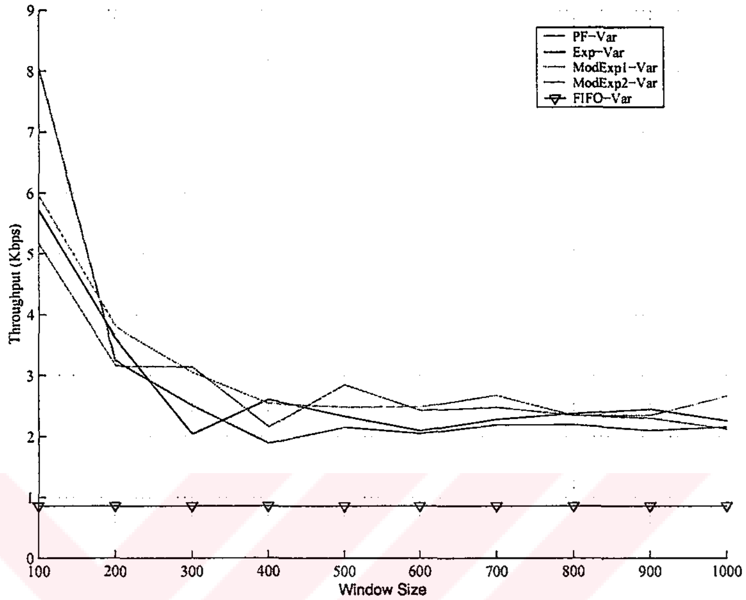

Figure 4.23: System Throughput Variance versus Window Size for the IS-856 System with 3 slot delay for Combined System

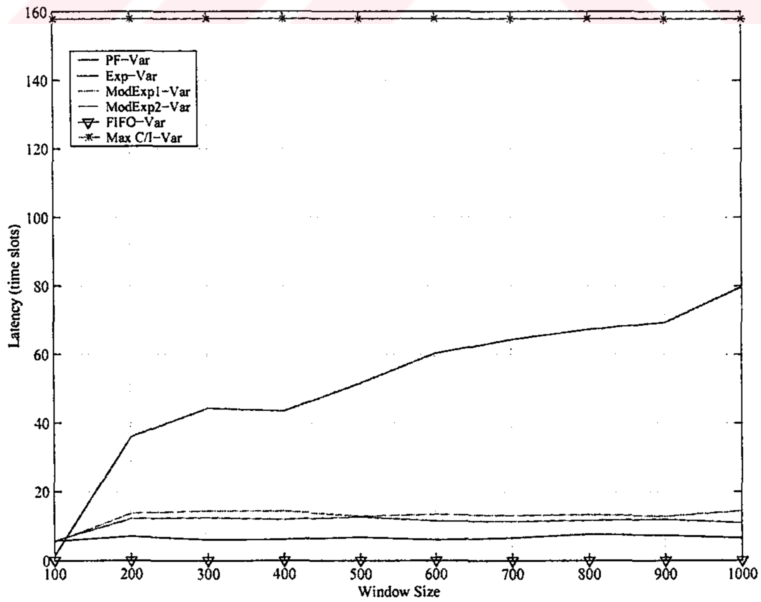

Figure 4.24: Observed Latency Variance versus Window Size for the IS-856 System with 3 slot delay for Combined System

4.5.3 Multi-Service Simulation Results

In this case, the thesis proposes multi-service provisioning to the IS-856 system and investigates the performance of the IS-856 system when this offering is employed. The system is designed that services falling into three QoS classes are being offered in the system. These services range from a highly delay tolerant service to a strict delay tolerance. Intuitively, one can imagine that the strict delay guarantees would reduce the overall performance of the IS-856 system. This is so, because the opportunistic multiple access nature of the system reaps gains by exploiting the variations in the wireless channel state of the users. When strict delay tolerance is required, the extent of exploitation in this front will decrease. This is indeed observed in the Figures 4.25-4.30. Here, system throughput as well as observed latency figures is plotted as a function of the number of users in the system for 3 km/hr, 30 km/hr, and 100-km/hr channels. The throughput and latency performances of the QoS classes are also compared individually in the graphs. The PF rule, the Exponential rule as well as the two new scheduling algorithms proposed in this thesis is used in the simulation.

The three QoS classes considered in the system are assumed to have the following service constants, $a_1 = 1/5$, $a_2 = 1/20$, $a_3 = 1/80$. Recall that these constants have their use in the scheduling algorithms directly as illustrated in the equations 3.17, 3.19, 3.21 and 3.23. In all these equations, the choice of the service constants determines the system throughput and the observed latencies. The QoS class, which has highest multi-service constant, observes minimum latency and maximum throughput. This QoS group contains following applications: VoIP, IP telephony, e-commerce transactions and streaming media. The QoS class that has lowest multi-service constant observes maximum latency and minimum throughput. This QoS group includes following applications: ftp, telnet, e-mail, web, chat, MMS, MP3 screening, wireless imaging, GPS location based services, multi-party games and e-banking. The multi-service constants are determined by related application group constraints.

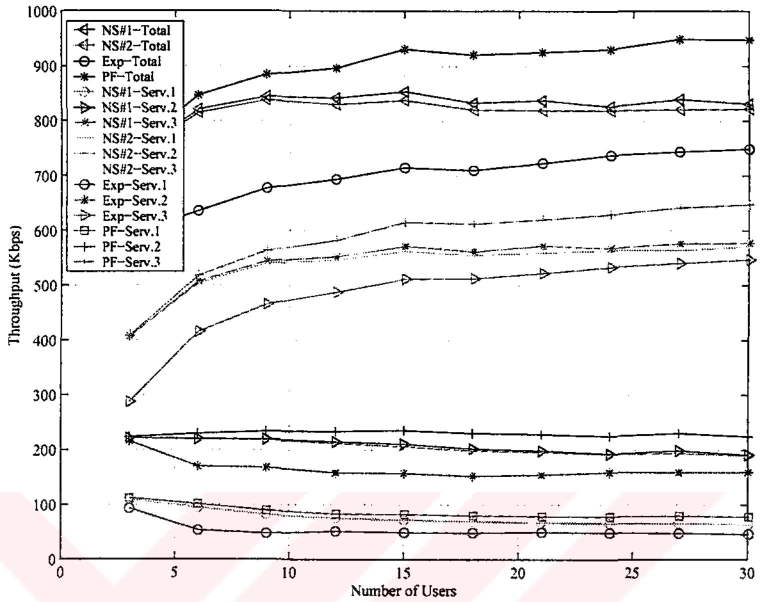

Figure 4.25: System Throughput versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 3 km/hr users

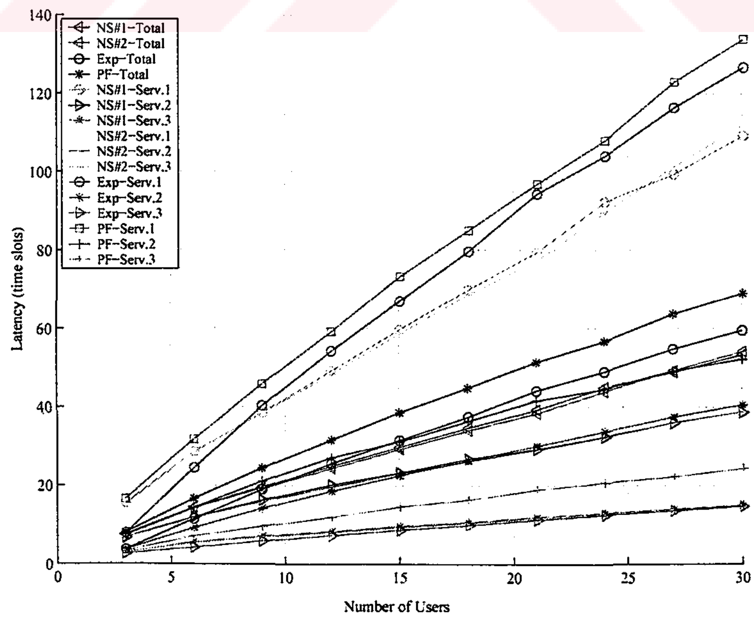

Figure 4.26: Observed Latency versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 3 km/hr users

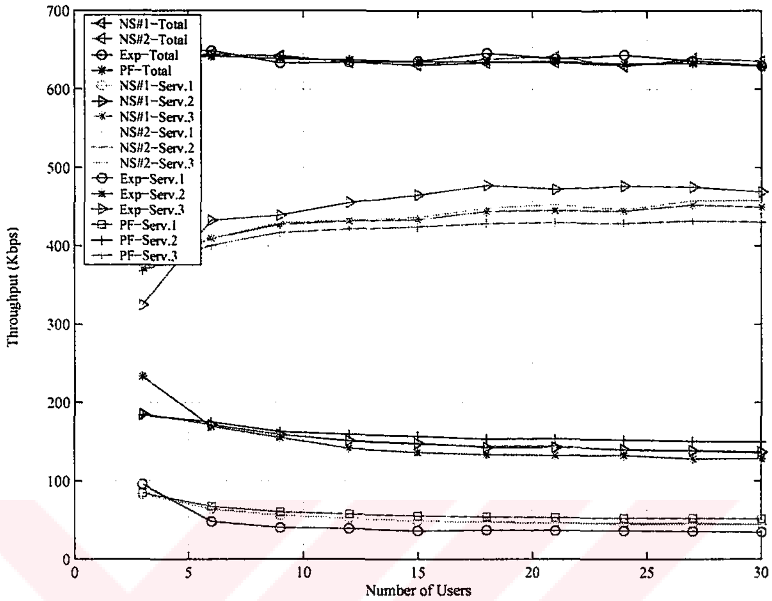

Figure 4.27: System Throughput versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 30 km/hr users

A typical delay requirement for one of the QoS classes would be in the form [28],

$$P(l_i > T_i) \leq \delta_i \tag{4.20}$$

where l_i is the average latency encountered by a user in the given QoS class, T_i is the maximum latency that this service can tolerate and δ_i is the probability that the system is allowed to violate this requirement. In this thesis, we set $\delta_1 = \delta_2 = \delta_3 = 0.01$.

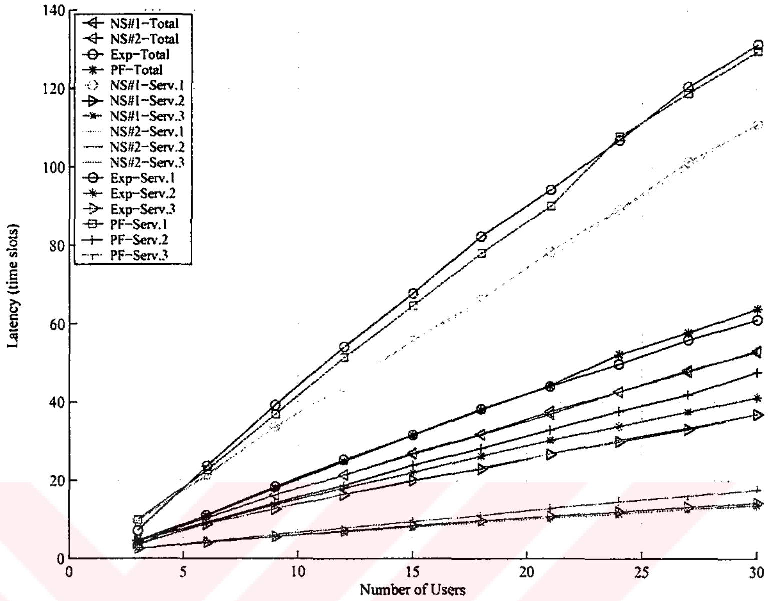

Figure 4.28: Observed Latency versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 30 km/hr users

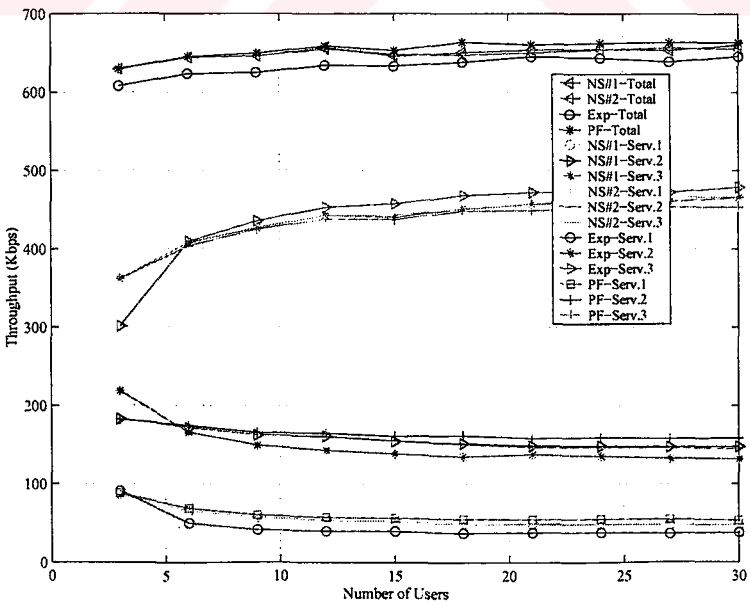

Figure 4.29: System Throughput versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 100 km/hr users

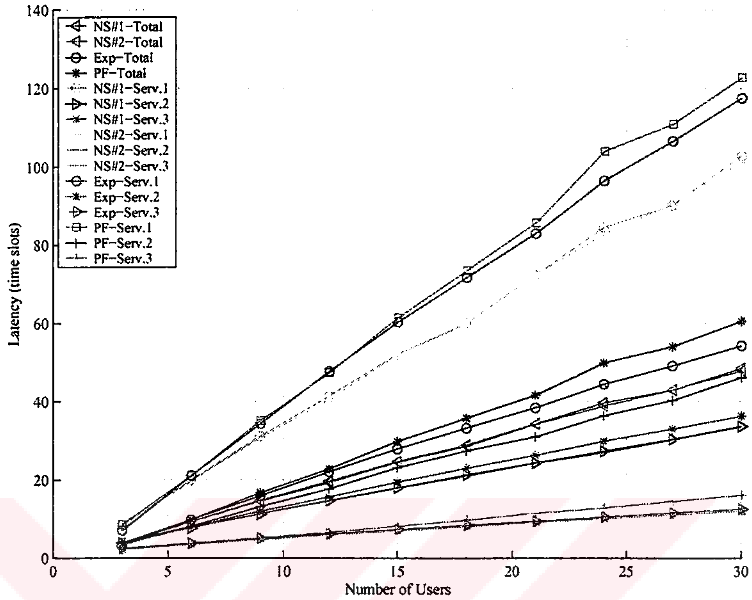

Figure 4.30: Observed Latency versus Number of Users for the Multi-Service IS-856 System with 3 slot delay for 100 km/hr users

[28] states that large deviation optimality results indicate that a good choice for a_i would be,

$$a_i = -\frac{\log(\delta_i)}{T_i} \tag{4.21}$$

The three services envisioned in this experiment are assumed to have delay tolerances of at most 0.0167 seconds, 0.0668 seconds and 0.267 seconds, respectively.

Comparing Figures 4.25-4.30 to Figures 4.9-4.14, it can be observed that when at least one QoS classes has relatively tight delay constraints, the overall throughput performance of the IS-856 system drops. Furthermore, as before, the throughput performance differences of the different schedulers are obvious only at low Doppler frequencies. When the Doppler frequencies are high, all algorithms have similar throughput performances. It cannot be said of the average latency performance however. As with the previous experiments, the multi-service case also observes higher latency figures with the PF rule. The two proposed schedulers are, once again, observed to have the best balancing performance of the throughput and the average latency for all QoS classes.

The 3 km/hr system enjoys an overall throughput of around 950 kbps with 30 users present. For the same number of users, the new algorithms provide 850 kbps whereas the exponential rule provides around 750 kbps. The 30 km/hr and 100 km/hr system on the other hand enjoys a throughput of approximately 635 kbps and 650 kbps, respectively with all scheduling algorithms.

The individual QoS classes vary significantly in their performances as desired. For the 3 km/hr system with 30 users, the first service class achieves throughputs of 45-77 kbps, the 77 kbps provided by the PF rule and the 45 kbps provided by the exponential rule. The new rules provide approximately 63 kbps of throughput. At 100 km/hr, these values go down to 50 kbps with PF and new rules, and 35 kbps with Exponential rule. The observed latencies for this service class on the other hand are the highest among all QoS classes. Average latencies of 134-110 slots are experienced when 30 users are present at 3 km/hr. The PF rule results in 134 slots of latency, whereas the exponential rule expose 127 slots latency and two new rules result in 110 slots of latency on average. Average latencies of 123-102 slots are experienced when 30 users are present at 100 km/hr. The PF rule results in 123 slots of latency, whereas the exponential rule displays 117 and two new rules result in 102 slots of latency on average. These values remain mostly unchanged for the 30 km/hr mobiles.

The second QoS class has a slightly less tolerant delay profile and thus enjoys a higher average sum throughput. For the 3 km/hr system with 30 users, this class achieves throughputs of 160-225 kbps, the 225 kbps provided by the PF rule and the 160 kbps provided by the exponential rule. The new rules provide approximately 200 kbps of throughput. At 100 km/hr, these values go down to 150 kbps with all scheduling rules. With this QoS class, average latencies of 52-38.5 slots are experienced when 30 users are present at 3 km/hr. The PF rule results in 52 slots of latency, while the exponential rule examines 40.5 slots, and two new rules result in 38.5 slots of latency on average. Average latencies of 33.5-46 slots are experienced when 30 users are present at 100 km/hr. The PF rule results in 46 slots of latency, while the exponential rule examines 36 slots, and two new rules result in 33.5 slots of latency on average. These values remain mostly unchanged for the 30 km/hr mobiles.

Finally, the third QoS class is the least delay tolerant of all classes. Therefore, it provides the largest average sum throughput to its users. However, this obviously comes at the expense of a larger latency profile. For the 3 km/hr system with 30 users, this class achieves throughputs of 545-645 kbps, the 645 kbps provided by the PF rule and the 545 kbps provided by the exponential rule. The new rules provide approximately 575 kbps of throughput. At 100 km/hr, these values go down to 465 kbps with all scheduling rules. With this QoS class, average latencies of 15-24 slots are experienced when 30 users are present at 3 km/hr. The PF rule results in 24 slots of latency, whereas the exponential rule results in 15 slots of latency. The two new rules on the other hand result in 14.5 slots of latency on average. Average latencies of 12-16 slots are experienced when 30 users are present at 100 km/hr. The PF rule results in 16 slots of latency, whereas the exponential rule results in 12.5 slots of latency. The two new rules on the other hand result in 12 slots of latency on average. Once again, these values remain mostly unchanged for the 30 km/hr mobiles. In conclusion, two proposed algorithms outperform in suggested multi-service environment.

4.5.4 Multicast Simulation Results

As expected, it can be observed that, for the 3-km/hr channel, performance of the IS-856 system with 10% of the population in multicast is slightly lower than the system with no multicast support. The relative performance ranks of the scheduling rules do not change in this experiment. Once again, the PF rule provides a slightly higher system throughput, but at the expense of an increased latency performance. The two proposed schemes seem to provide for the best overall performance of throughput and latency values, once again. At 100 km/hr and 30 km/hr, the multicast operation impact on the system throughput is almost non-existent as the system performs almost on par with the non-multicast system of the single server case as seen in Figure 4.31-4.36.

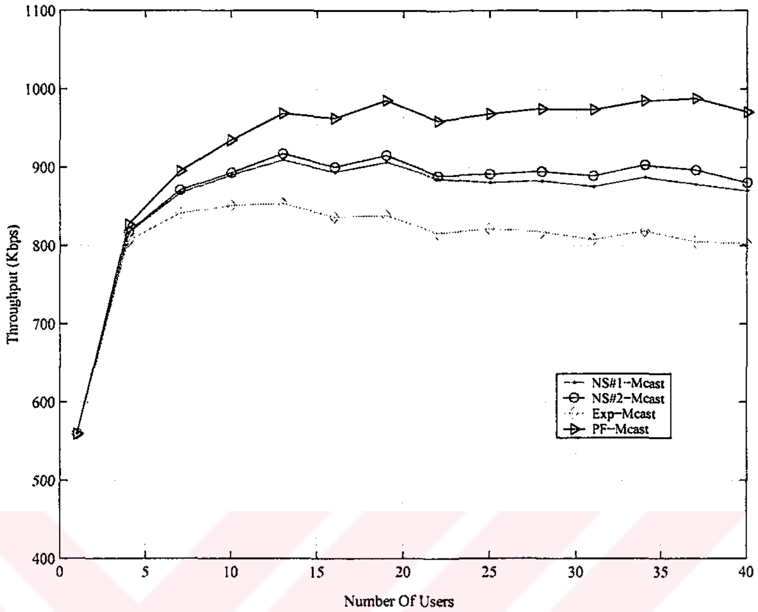

Figure 4.31: System Throughput versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 3 km/hr users

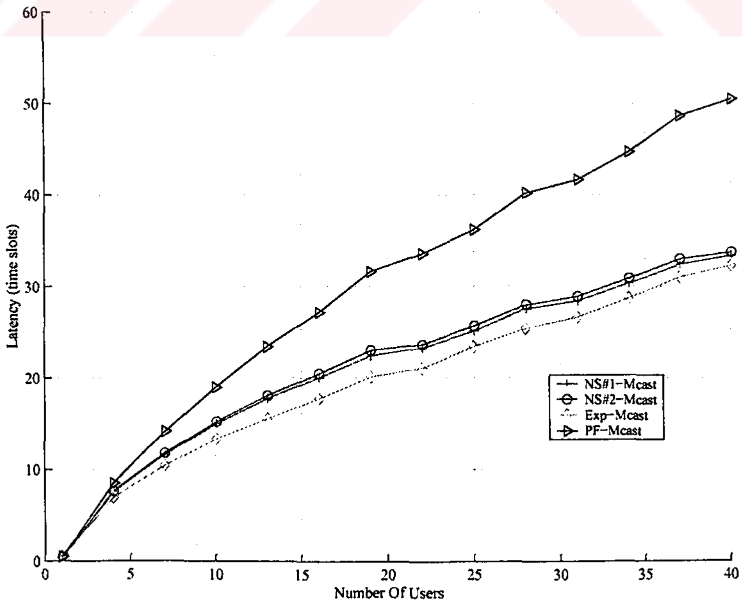

Figure 4.32: Observed Latency versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 3 km/hr users

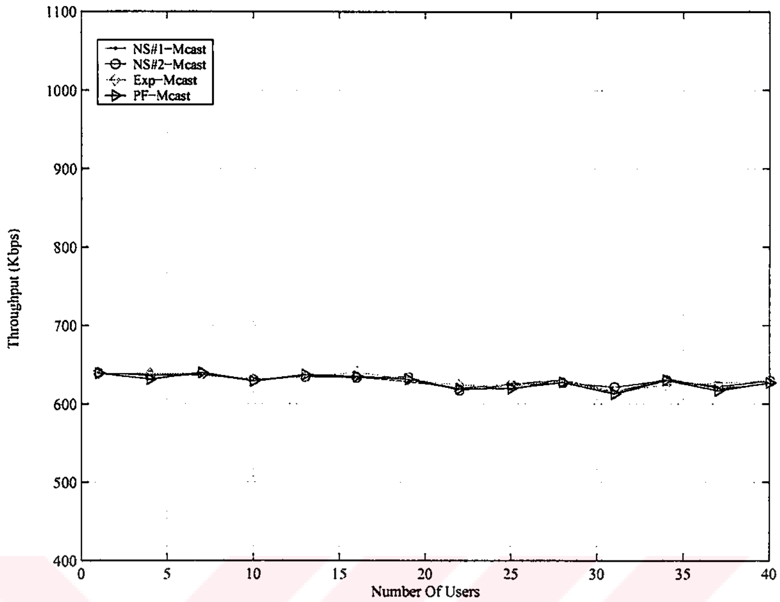

Figure 4.33: System Throughput versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 30 km/hr users

4.6 Conclusions

This chapter presents means of single-service, combined structure, multi-service, and multicast provisioning in a spectrally efficient manner in wireless communications. The IS-856 system, which takes much of its characteristics from the information theoretic findings of the literature, is an efficient air interface to provide delay tolerant wireless packet data. The scheduling algorithm in the system provides for proper resource allocation, which allows for the exploitation of the multi-user diversity. A

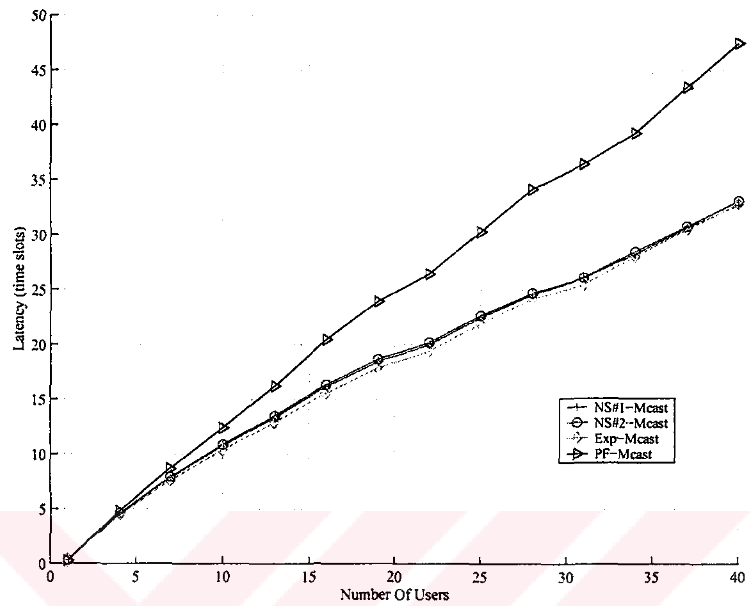

Figure 4.34: Observed Latency versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 30 km/hr users

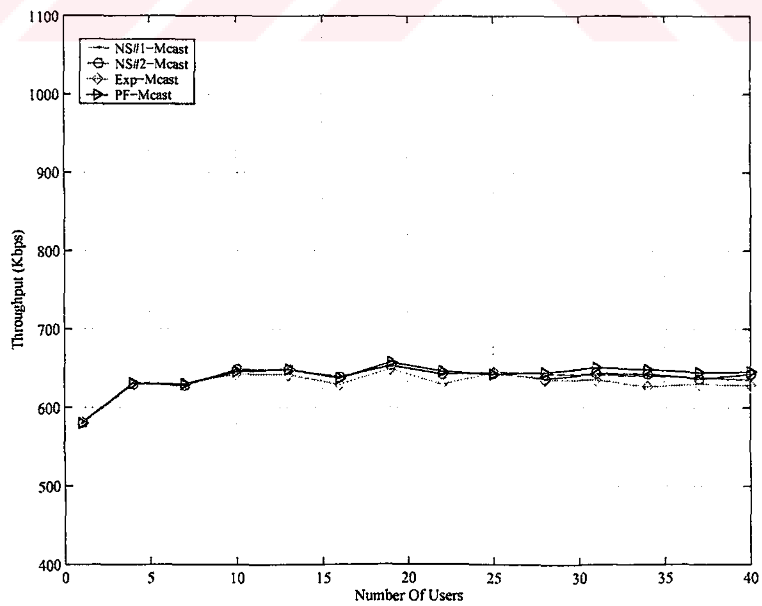

Figure 4.35: System Throughput versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 100 km/hr users

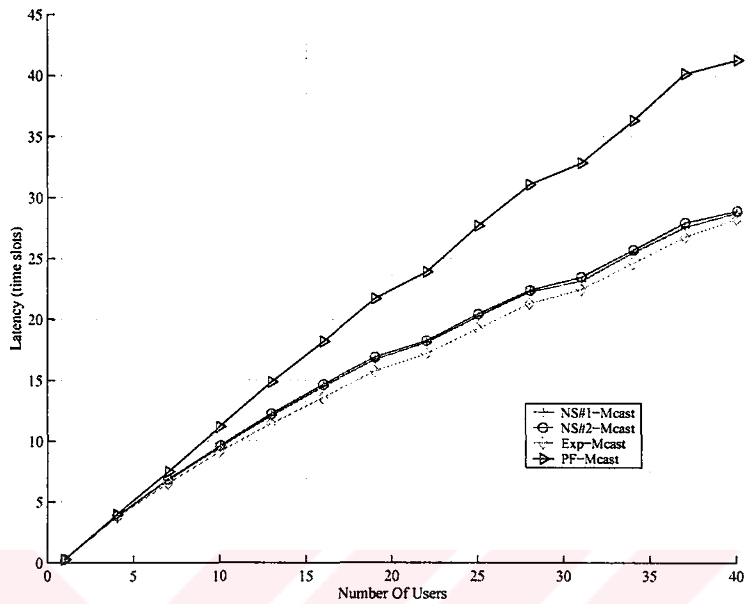

Figure 4.36: Observed Latency versus Number of Users for the IS-856 System Supporting Multicast with 3 slot delay for 100 km/hr users

number of scheduling algorithms have been simulated in this chapter, namely the Maximum C/I rule, the FIFO rule, the proportionally fair (PF) algorithm proposed by Qualcomm [27], the exponential rule [28], the modified Longest Weighted Delay First (M-LWDF)[29], hybrid of the maxD and PF algorithms maxD/PF-0.25 and maxD/PF-0.75 [31], and the five new scheduling algorithms. The performance of the scheduling rules need to be assessed based on not only the system throughput performance, but also the average latency performance. In all instances considered in this chapter, four of the new algorithms provide for a very good overall performance in yielding good throughput values all the while maintaining latency figures close to those of the optimal values. Then, two of proposed fair algorithms are selected to utilize multi-service and multicast service provisioning.

Second, to investigate the feasibility of providing a multitude of services, with different QoS requirements on the IS-856 system in this chapter. The scheduling algorithm will need to take input from the various QoS classes that may be formed in this case. Based on the channel characteristics, user latencies and now, the QoS classes the schedulers need to perform resource allocation to ensure acceptable performance for all services.

Extensive simulations have been conducted and it is observed that it is possible to provide different services using the IS-856 system.

A possible way of providing multicast service provisioning in the IS-856 system is also described in this chapter and performance results are given. The IS-856 system can very easily accommodate such a service in its current form.

Chapter 5

IS-856 SYSTEM PRACTICAL CONSIDERATIONS: TWO USERS AT A TIME SYSTEM

The Forward link structure like shown in Figure 2.3 that offers some advantages when the all Walsh codes are assigned to a single user with a time division multiplexed fashion. The striking advantages are no intracell interference and saving synchronization overhead due to giving a service only one user [61]. Pilot bits transmitted with a full power to the requested user. These benefits outcome high Signal to Noise Ratio (SNR), namely, base station transmits a data with a high data rate. As explained Chapter 2, Forward Traffic Channel is transmitting at full power. This system is the best way for data traffic that produces the highest peak data rate and cell throughput.

Notwithstanding, all Walsh codes are assigned to the different users, the average observed latencies are dropped sharply. Yet, this is not ideal for data communication. Some applications are not delay tolerant such as streaming video. To give service, the IS-856 system [10] observed average latency must not be passed a certain level. In addition to data applications, if the system contains a mixture of data and voice users, Walsh Channels are carefully assigned to any particular user to decrease observed average latency. To extend the versatility of the IS-856, the trend starts from the Time Division Multiplexed fashion to Code Division Multiplexed fashion [61].

According to findings of [61], the chapter offers new access system, which is called *Two Users At A Time System*, and two new scheduling algorithms to maintain this proposed system. The difference between the IS-856 system and Two Users At A Time System is arranging Walsh Codes. In IS-856 system, 16 Walsh Codes are assigned only one user, on the other hand, in Two Users At A Time System, 1 Walsh Code is reserved for Control and the rest is used orthogonally as two users data if the channel conditions support two-user scheme. If the system does not maintain two users at that time instant, one user may utilize all Walsh Codes. Due to presence of second user in the system, the minimum required E_c/I_o values are also increased a little bit.

5.1 Two Users At A Time System Physical Layer Simulations

The new system maintains all data rates ranging from 38.4 kbps to 2.457 Mbps are supported in the IS-856 system using adaptive coding, modulation and varying physical layer packet sizes. The Agilent's ADS 2002C simulator was again used to realize extensive physical layer simulations. The building blocks of IS-856 are explained in Chapter2. In all cases, both the data and the preamble performances have been investigated. A target physical layer packet error rate of 1% is assumed for all cases. The minimum required E_c/I_o and E_b/N_t levels have been found for an AWGN channel. The physical layer simulations have not considered the fading, multipath because these parameters are already included in the system level simulations as explained chapter 4. The underlying assumption here is that within a time slot of 1.67 ms, the C/I level for a mobile remains unchanged. The physical layer simulation results are showed in Table 5.1.

5.2 Two Users At A Time System Resource Allocation Simulations

Obtaining the data from the system and physical layer simulations, the performance of the Two Users At A Time system when the schedulers described in the next section are employed. Single server scenario is envisioned. The goal is to investigate the performances of the proposed schedulers in terms of the system throughput and user experienced average latency.

For each of the users present in the system, C/I levels for 18,000 successive time slots (30 seconds) are determined from the cdf distribution of Figure 4.2 which was developed through the system level simulations. Depending on the individual speeds of the mobiles, these streams of values are passed through the designed FIR filters to incorporate the corresponding Doppler effects. The physical layer simulations shown in Table 5.1 provide for the range of C/I values to ensure a 1% packet error rate transmission for all of the supported data rate classes. In the all simulations, a round-trip delay of 3 time slots is again taken into account.

5.3 Two Users At A Time Scheduling Algorithms

As said chapter 3, the most important part of the opportunistic multiple access communication system under study is the applied scheduling algorithm. The scheduler assigns the system resources to different users in a time-multiplexed fashion. The selection of the scheduling algorithm influences not only the system throughput but also the average delay exposed by users in between successive accesses to the system. Although the Two Users At A Time System newly proposed in this thesis, no scheduling algorithm is present in the literature, hence, the thesis suggests two new scheduling scheme: Modified Exponential-FIFO and Modified Exponential-Modified Exponential. In the next section, comparison will be made between the IS-856 system which uses the classical schemes, PF, Exponential rule, FIFO rule, Max.C/I, and Modified Exponential-1 & 2, and Two Users At A Time system utilizes new schedulers.

5.3.1 Modified Exponential-FIFO

In chapter 4, the thesis showed that PF algorithm is unfair with low Doppler speed users, yet, the Modified Exponential-1 & 2 are the good candidate for IS-856 system in various environment. Thus, Modified Exponential-1 is selected for first scheduler for suggested two users at a time system. Once more, if a_i's are the multi-service specific user values in a multi service system but all are equal in this scenario, in other words, single server case is applied. Mathematically, scheduler schedules first user

$$j = \arg\max_i \left(a_i \frac{r_i(kt_s)}{\overline{\overline{r_i(kt_s)}}} \right)^2 \exp\left(\frac{a_i\ l_i(kt_s) - \overline{a\ l(kt_s)}}{1 + \sqrt{\overline{a\ l(kt_s)}}} \right) \tag{5.1}$$

where

$$\overline{al(kt_s)} = \frac{1}{N} \sum_{i=1}^{N} a_i l_i(kt_s) \tag{5.2}$$

		Number of Walsh Codes														
Data Rate	Slots Used	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
38.4	16	-11.67	-11.47	-11.3	-10.97	-10.67	-10.33	-9.97	-9.51	-8.92	-8.29	-7.57	-6.47	-5.19	-3.07	-0.97
76.8	8	-9.24	-8.91	-8.68	-8.32	-7.84	-7.54	-7.04	-6.58	-5.99	-5.36	-4.64	-3.54	-2.26	-0.14	1.96
153.6	4	-6.1	-5.77	-5.54	-5.18	-4.70	-4.40	-3.90	-3.44	-2.85	-2.22	-1.50	-0.40	0.88	3.0	5.1
307.2	2	-2.91	-2.59	-2.36	-2	-1.52	-1.22	-0.72	-0.26	0.33	0.96	1.68	2.78	4.06	6.18	8.28
614.4	1	-0.7	-0.3	-0.2	0.68	1.1	1.5	1.7	1.8	2.4						
307.2	4	-3.71	-3.11	-2.61	-2.13	-1.71	-1.31	-1.11	-1.01	-0.41						
614.4	2	-0.9	-0.3	0.2	0.68	1.10	1.5	1.7	1.8	2.40						
921.6	2	1.66	2.26	2.68	3.28	3.88	4.78	5.6	7.18							
1228.8	1	3.72	4.32	4.82	5.3	5.72	6.12	6.32	6.42	7.02						
1843.2	1	8	8.6	9.02	9.62	10.22	11.12	11.94	13.52							
1228.8	2	3.82	4.28	4.92	5.52	6.12	7.02	8.22								
2457.6	1	11.2	11.64	12.34	12.94	13.54	14.44	15.64								

is the average of the weighted latencies observed by all of the N users in the system at time slot k. If user channel condition supports second user as demonstrated in Table 5.1, then, the scheduler uses FIFO rule to select second user as explained in chapter 3. Mathematically, scheduler schedules at time slot k, the second user,

$$j = \arg\max_i \; l_i(kt_s). \tag{5.3}$$

where i is not equal to first scheduler selected user.

5.3.2 Modified Exponential-Modified Exponential

The previously suggested algorithm, Modified Exponential-FIFO, is very delay strict algorithm, namely, the overall throughput should be low. To prevent this unwanted situation, the thesis recommended that the second scheduler, FIFO, will replaced with Modified Exponential-1 which utilizes user diversity to increase throughput. If user channel condition supports second user as demonstrated in Table 5.1, then, scheduler schedules first and second users with equation , otherwise, the scheduler gives a service to one user with same equation.

5.4 Two Users At A Time System Simulation Results

In 3-km/hr channel, when the 30 users present in the system as anticipated FIFO rule gives the lowest throughput around 500 kbps, the Max.C/I rule provides approximately 1 Mbps is the highest throughput. As depicted in chapter 4, the PF rule maintains again 950 kbps, and the newly proposed schemes for the IS-856 system nearly 100 kbps less throughput (880 kbps) and the exponential rule services 820 kbps. The two users at a time first scheduler algorithm supports almost Exponential rule 825 kbps, and the second proposed scheme, Modified Exponential-Modified Exponential, sustains more or less PF rule.

¿From the latency point of view, the scheduling algorithms rank as follow: The Max.C/I, obviously, is the highest latency with 48 time slots, the second place is occupied PF with 40 time slots, the third is Modified Exponential-1 & 2 with 27 time slots, the exponential rule is the fourth with 25 time slots, the fifth is FIFO rule with 18 time slots, the Modified Exponential-Modified Exponential is the sixth place, and then Modified Exponential-FIFO is ordered the last row. If two scheduling algorithm have same throughput, the one has a lower latency is better scheme than the other. According to this results, the two user at at time system is superior than the IS-856 system in 3-km/hr channel as seen in Figure 5.2-5.3.

In 30 km/hr, when the 30 users sit in the cellular environment, the Modified Exponential-Modified Exponential supports 700 kbps, the FIFO rule supplies 600 kbps, the Modified Exponential-FIFO gives 620 kbps, and the others maintains 630 kbps. The latency rank is not changed too much but the values are a little bit better due to fast changing channel. The order is the Max.C/I, PF, Modified Exponential-1 & 2 and Exponential rule, the FIFO rule, and the two newly proposed two users at a time scheme with 40 time slots, 34 time slots, 25 time slots, 17 time slots, and 13 time slots, respectively. In 30-km/hr channel, again, the two users at a time system is better than the IS-856 system more Figure 5.4-5.5.

If the 30 users utilize the both systems in 100-km/hr channel, the Modified Exponential-Modified Exponential results 720 kbps, the FIFO rule obtains 600 kbps, the Modified Exponential-FIFO gets 630 kbps, and the others provides 670 kbps. The observed latency point of view, the IS-856 system scheduling algorithms are experienced the highest latency figures, the two users at a time scheduling algorithms result the lowest latency figures in 100-km/hr channel. The Modified Exponential-Modified Exponential is the best scheme all of the scheduling algorithms as demonstrated in Figure 5.6-5.7.

5.5 Conclusion

In this chapter mainly talks about a new system, two users at a time, which eliminates the high latency values of the IS-856 system to support delay intolerant applications and additionally increases the system throughput. Moreover, new scheduling algorithms is also need for this new system, for this reason, two new scheduling algorithms are presented. One of the scheduler, the Modified Exponential-Modified Exponential,

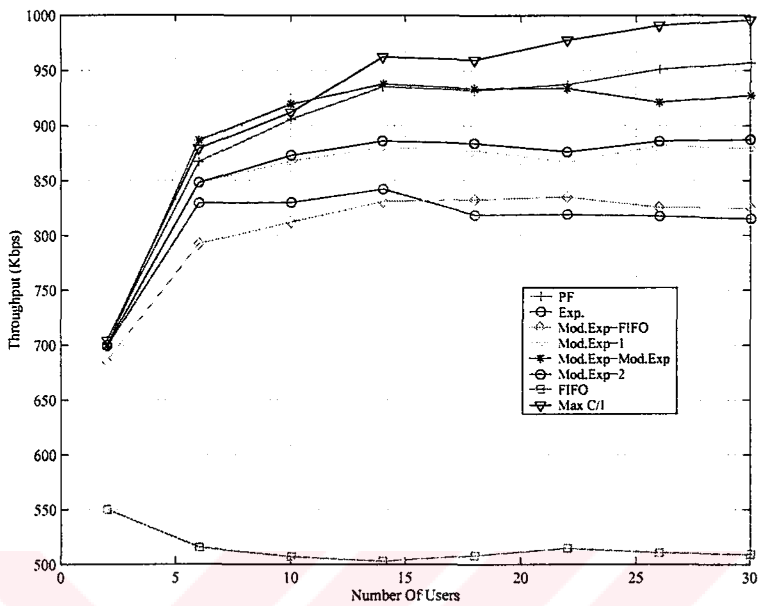

Figure 5.2: System Throughput versus Number of Users for the Two Users At A Time System with 3 slot delay for 3 km/hr users

gives the very latency without too much hurt system throughput in 3-km/hr channel, and supports the highest throughput and lowest latency in 30 km/hr and 100-km/hr channels.

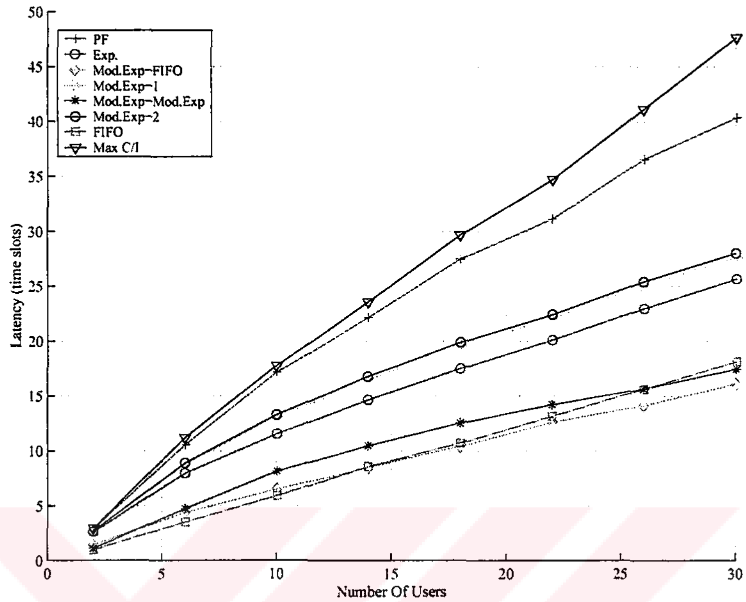

Figure 5.3: Observed Latency versus Number of Users for the Two Users At A Time System with 3 slot delay for 3 km/hr users

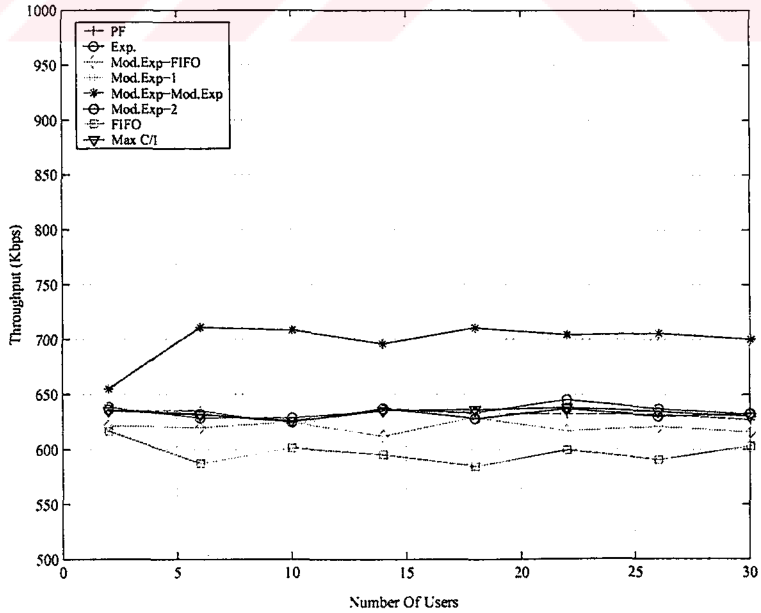

Figure 5.4: System Throughput versus Number of Users for the Two Users At A Time System with 3 slot delay for 30 km/hr users

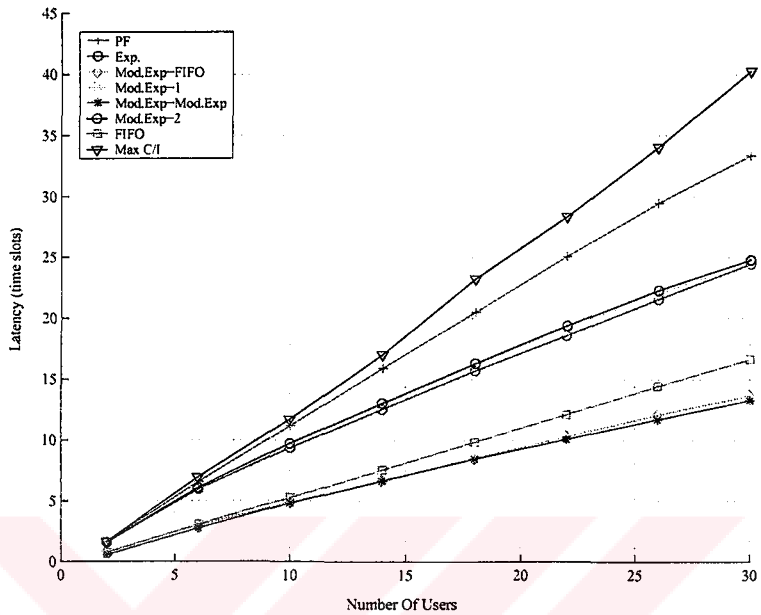

Figure 5.5: Observed Latency versus Number of Users for the Two Users At A Time System with 3 slot delay for 30 km/hr users

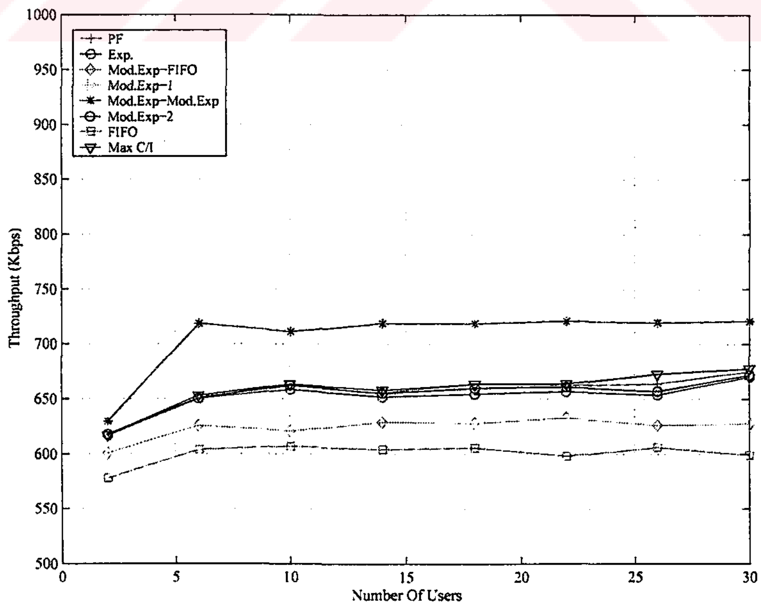

Figure 5.6: System Throughput versus Number of Users for the Two Users At A Time System with 3 slot delay for 100 km/hr users

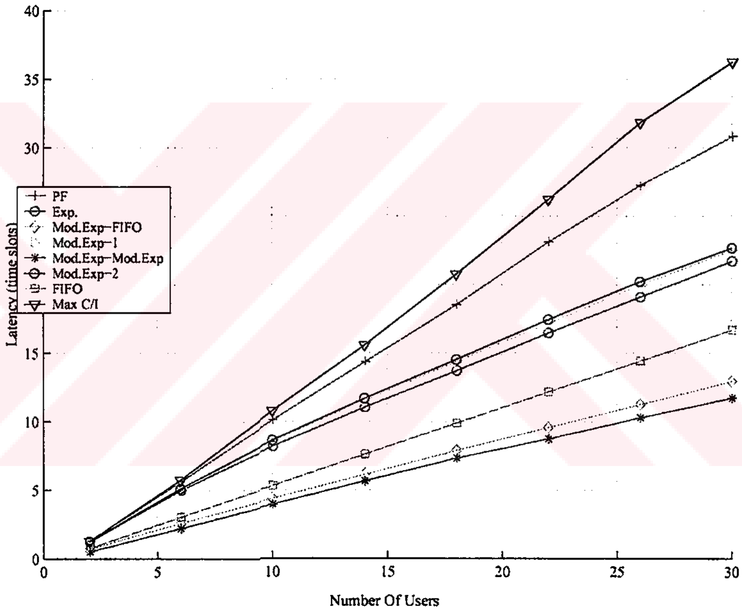

Figure 5.7: Observed Latency versus Number of Users for the Two Users At A Time System with 3 slot delay for 100 km/hr users

Chapter 6

WIRELESS LOCAL AREA NETWORKS OVERVIEW

Especially last decade, the number of wireless communication products such as pagers, and cellular phones has increased enormously. Using these products, billions of people exchange information. Due to great achievement of these devices it is obvious that wireless communication products and technologies support personal and business computing facilities.

The grounds of changing wired technologies to the wireless one is mobility. Classical wired networks that users must be connected to a network by cables have sustained insufficiently to cover today's need. On the contrary, wireless networks do not bring about mobility restrictions and permit more free movement. New technologies targeted at computer networks promise to connect with each other regardless of location.

Although the final goal of this thesis is not learning the topology of the wireless local area networks but if the network engineer tries to combine two different network topologies, both of the network structures, design parameters and riddles, and MAC and Physical layers should be understood clearly. The IS-856 system is already explained in chapter 2, so, this chapter will try to explain importance of wireless networks, IEEE 802 network technologies and network architectures, MAC layer design challenges, IEEE 802.11 Physical layer overview and RF components, Orthogonal Frequency Division Multiplexing (OFDM), and overview of IEEE 802.11 standards will be explained successively.

6.1 Why Wireless Networks?

Wireless networks contribute various important advantages. The most conspicuous advantage of wireless networking is mobility. Users can connect easily to existing networks and permit to roam freely. A cellular phone user may travel tens of kilometers without interruption of his/her conversation. Due to mobility, people can use wireless networks in many places such as in the library, in the faculty, in the office, or in the stock exchange. The list of the places is continued to infinity. The limit is the design engineer's imagination.

Likewise mobility, flexibility is the other key advantage that can save time for preparation. In wired networks, adding an extra user needs cables, punching down terminals, and a new jack but in wireless side, once that infrastructure is built, operator just sets up infrastructure properties. Flexibility is also a vital dimension for "hot spot" connection. Hot spot is a small area where the number of wireless subscribers' density is the highest. Airports, coach stations, or seaports are very attractive places for building hot spot. With building a hot spot, no construction is needed.

Flexibility has got some benefits when dealing with older buildings since they decline maintenance costs. If the building is announced historical, no one can be easily installed the cables through the building. Wireless networks can be assembling in these surroundings.

The last but the most important property of the wireless local area network for the service providers is radio spectrum since spectrum is the most expensive part of the communication system. Wireless networks utilize ISM bands that are generally license-free. The most common used ISM bands are S-Band ISM (2.4-2.5 GHz) and C-Band ISM (5.725-5.875 GHz).

With respect to equipment, the IEEE 802.11 standard has gained more famous than Bluetooth and Third Generation (3G). Then, Apple started to produce equipments for IEEE 802.11. Table6.1 is a comparison of the different IEEE 802.11 standards.

6.1.1 WLAN Merging with Others

One might asks that why people deal with the difficult problem of seamlessly roaming from one type of network (e.g., WLAN) to another type of network (e.g., cellular, LAN, etc.) or vice versa. The answer is that wireless local area networks are the super ordinate solution for providing next generation wireless services to indoor and campus hot spots and WLANs can manage large volumes of data at significantly lower costs, offer a migration path to speeds of 100 megabits per second and higher [62]. In Chapter 7, a new type of routing protocol, cooperates both IEEE 802.11a and IS-856, will be explained. With access to these two network types, mobile users can realize data speeds of up to 650 kbps on IS-856 (3G networks) and up to 54 megabits per second (Mbps) on 802.11a WLANs. The combined throughput of IS-856 is obviously more than 1 Mbps.

The key points are battery life, and mobile station receiver capabilities. The latter, receiver structure, can be easily changed to operate both 2 GHz and 5 Ghz but the battery life is still crucial problem. The thesis scope is not dealt with extending battery life but to increase battery usage equity, a new type of fairness is added to routing protocol and is called *utility factor.* This technique is to enable seamless and secure inter-technology handoffs between 802.11a and IS-856; a technique made possible by only mobile network architecture was initiated.

6.2 IEEE 802 Network Technologies

IEEE 802.11 is a group of local area network (LAN) specifications that is under the IEEE 802 family tree. Figure 6.1 depicts several IEEE 802 specifications and positions in the OSI reference model.

IEEE 802 specifications cover both a MAC and Physical layers of equipment. MAC layer is a set of rules which decides accessing the media and data transmission; on the other hand, signal propagation and receiver parts are dealt with in the Physical layer.

IEEE 802.11 is not only a kind of link layer IEEE 802.2 because IEEE 802.11 sets aside mobile network access. The early IEEE 802.11 specification contains the 802.11 MAC and two physical layers. These are a frequency-hopping spread-spectrum (FHSS) physical layer and a direct-sequence spread-spectrum (DSSS) link layer. Afterwards, IEEE 802.11b and IEEE 802.11a are added to increase achievable data rate [70].

IEEE Standard	Speed	Frequency Band	Comments
802.11 [65]	1 Mbps 2 Mbps	2.4 GHz	Standardized in 1997. Uses both frequency-hopping and direct-sequence modulation techniques.
802.11a [66]	6 Mbps to 54 Mbps	5 GHz	Standardized in 1999. Higher data rate and support better protection against possible interference from neighboring access points.
802.11b [67]	5.5 Mbps to 11 Mbps	2.4 GHz	Standardized in 1999. Installations may suffer from speed restrictions in the future and higher interference from neighboring access points.
802.11g [69]	Up to 54 Mbps	2.4 GHz	Standardized in 2003. Speeds similar to 11a and backward compatibility may appear attractive but too complex compared with 11a. However, there are advantages for vendors looking to supply dual-mode 2.4 GHz and 5 GHz products, in that using OFDM for both modes will reduce silicon cost.

Table 6.1: IEEE 802.11 Standards Comparison

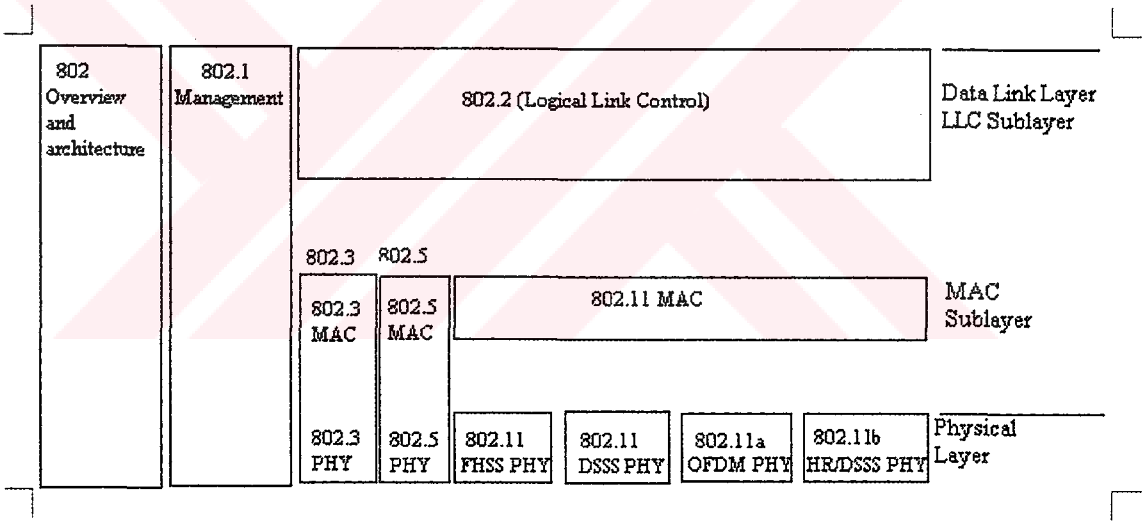

Figure 6.1: The IEEE 802 family and its position in the OSI model

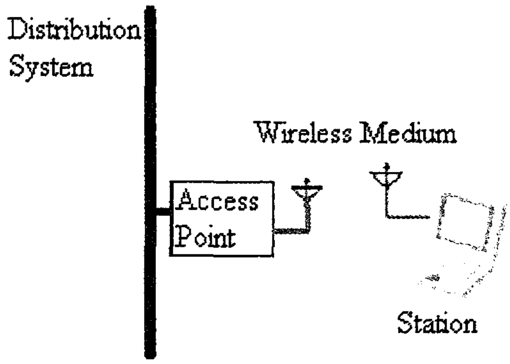

Figure 6.2: Components of IEEE 802.11 LANs

IEEE 802.11 networks include four major physical components: Distribution system, Access point, Wireless medium, and Station as depicted in Figure 6.2.

6.3 IEEE 802.11 Network Architectures

The IEEE 802.11 specification allows the designer to build two different network topologies. The first topology is called ad-hoc or independent networks that are a group of computers that communicate with each other without structure, and fixed points. Stations in an ad hoc network communicate directly with each other and thus must be within direct communication range as seen in Figure 6.3. It is hardly surprising that supporting ad hoc type network is very difficult since ad-hoc networks encounter limited resources, no established network topology, and frequent disconnections.

To keep up network lifetime for ad hoc networks is the most important concept. If one considers mixed networks (e.g. IS-856 and IEEE 802.11a) decreasing power consumption is a challenging research topic in the next decade. It is clear that data transfer consumes much of the power rather than sensing and processing [63, 64]. There are several sources of energy waste such as *collision*. Collision is usually stems from the *hidden node problem* is that one user receiving a data more than one user at the same time or sending a data to each other as seen in section 6.4.1. Due to collision, latency and power consumption increase. In the recent publications [65, 71], depict how to combat hidden node problem.

The second power consumption source is *overhearing*, that is receiving data, which are sent to neighboring nodes. The third power consumption mechanism is *packet overhead.* Control packets help receiver to synchronize incoming signal and update routing information, however, they consume energy and bandwidth. Another important energy consumption source is *listening.* It is a kind of monitoring the network whether sent packet or not. Researches have been conducted that 50−100% of the receiving power is consumed when the network is idle listening [63, 72, 73].

In addition to energy constraint, low bandwidth, high bandwidth variability, high error rates, possible asymmetric connectivity, hidden terminal problem, low resource machines, higher delay, disconnected operations, and proximity needs are the common characteristics of the ad hoc networks. Future networks which should be utilized from ad hoc structure to support both WLANs and 3G telecommunication networks are considered to handle features of ad hoc networks.

The second type of the network topology used in wireless local area networks is the infrastructure. Access points separate infrastructure networks as seen in Figure 6.4. If two mobile stations communicate each other first of all, the transmit station sends a frame to the access point, then, the access point transmits the frame to the receiver station. This multihop communication might look more costly in the terms of transmission capacity but it has significant advantages over ad hoc networks. Some occasions of this topology is that no restriction is present for the distance between mobile stations and access points helps the station to save power.

IEEE 802.11 supports following network operations: Distribution, Integration, Association, Reassociation, Disassociation, Authentication, Deauthentication, Privacy, and *MSDU delivery[64]*.

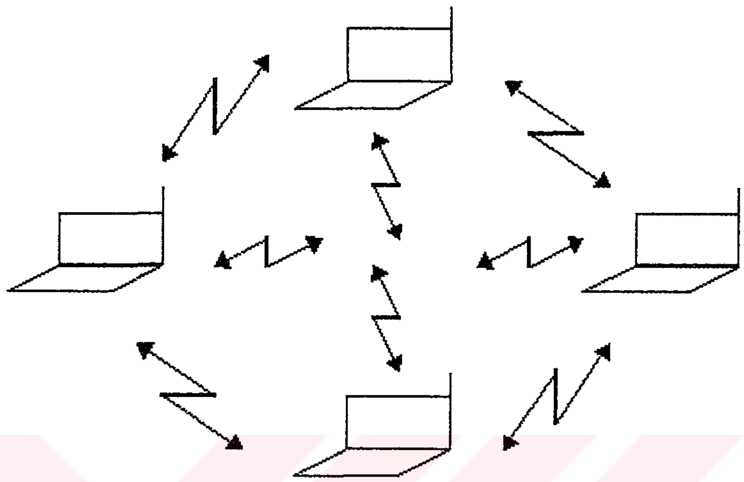

Figure 6.3: Ad-Hoc Network

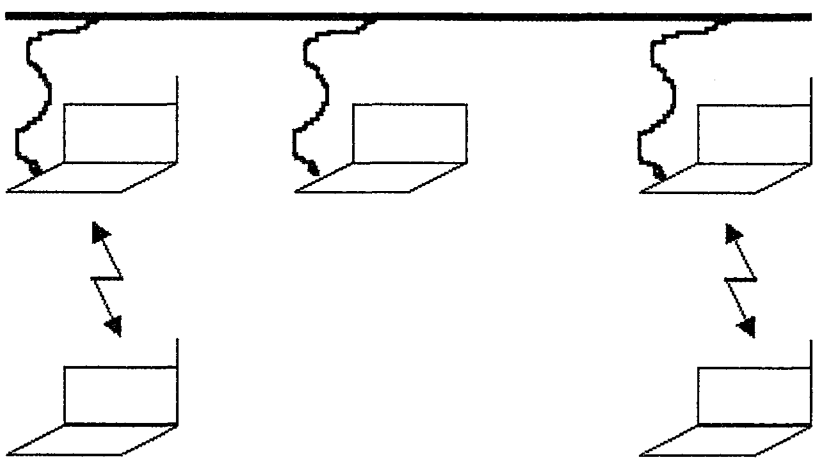

Figure 6.4: Infrastructure Network

6.4 MAC Layer Design Challenges

Compared to the wired media, network engineers have confronted with additional difficulties in wireless media such as RF link quality, and hidden node problem. When dealing with ISM bands RF link quality is an important problem since many RF sources work around and interfere transmitted signal. In addition to interference, multipath and fading attenuate the transmitted signal. Nevertheless, IEEE 802.11 takes into account positive acknowledgments. All transmitted frames must be acknowledged, otherwise, the frame is considered lost.

6.4.1 The Hidden Node Problem

The Hidden Node Problem usually occurs on a wireless local area networks [74, 75, 76, 77, 78]. Due to their limited transmission ranges; A and C cannot hear each other and if they transmit at the same time to B, their frames could be corrupted as in Figure 6.5.

IEEE 802.11 solves this problem by adding two additional frames: a request to send (RTS) frame and a clear to send (CTS) frame. Source sends RTS and destination replies with CTS and nodes that here RTS and CTS suspends transmission for a specified time indicated in the RTS/CTS frames as seen in Figure 6.6. If target station hears RTS frame then it sends CTS frame. If CTS does not hear from the sender, it is treated as a collision, and the rules for scheduling the retransmission are described in the section on the basic access mechanism. Once the RTS/CTS exchange is complete, source can transmit its frames without worry of interference from any hidden nodes. If the RTS/CTS clearing procedure is used, any frames will be positively acknowledged.

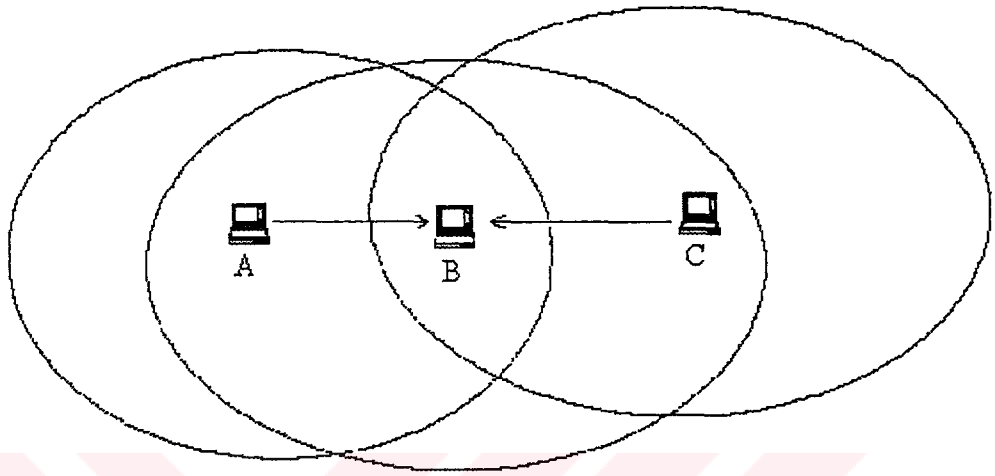

Figure 6.5: The Hidden Node Problem

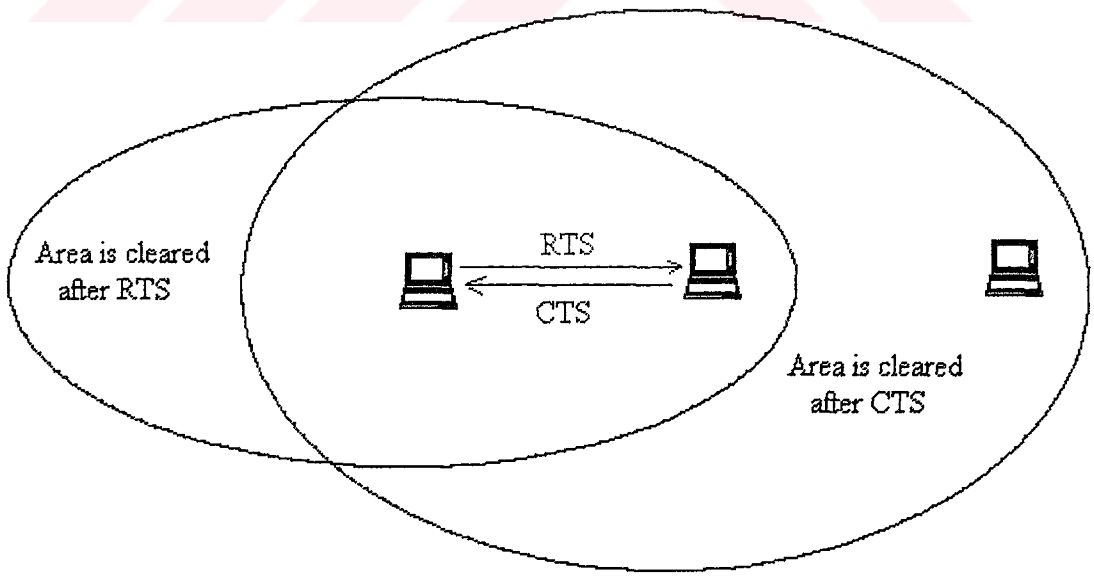

Figure 6.6: RTS and CTS address the Hidden Node Problem

6.5 IEEE 802.11 Physical Layer Overview

6.5.1 IEEE 802.11 Physical-Layer Architecture

The *Physical Layer Convergence Procedure* (PLCP) sublayer and the *Physical Medium Dependent* (PMD) sublayer are sublayers of the physical layer. The PLCP is the transitive sublayer between physical medium and the MAC layer. PLCP appends its own header to the sending frame. The function of PMD is to transmit bits at the sender side and to receive transmitted bits at the receiver [65].

6.5.2 IEEE 802.11 Radio Link

In 1997, three physical layers were standardized: Frequency-hopping (FH) spread-spectrum radio physical, Direct-sequence (DS) spread-spectrum radio physical, infrared light (IR) physical [65]. In 1999, two more physical layers were originated: 802.11a: Orthogonal Frequency Division Multiplexing (OFDM) physical [66], and 802.11b: High-Rate Direct Sequence (HR/DS or HR/DSSS) physical [67]. Due to High Data Rate needs, this thesis explains mostly IEEE 802.11a, IEEE 802.11b and IEEE 802.11g.

Unlicensed Frequency Bands

FCC and its similitudes' reserved certain frequency bands that are called ISM bands, for the use of industrial, scientific, and medical equipments. These frequency bands are unlicensed, namely, companies do not pay money to use ISM bands like microwave ovens work at 2.45 GHz but they must obey the radiation limits and transmitted power levels.

In USA, three more unlicensed bands are present at 5 GHz: 5.15-5.25 GHz, 5.25-5.35 GHz, and 5.725-5.825 GHz. In Europe, first two bands are reserved for HIPERLAN, and the third band is dedicated for 802.11 wireless networks.

Spread Spectrum

Spread spectrum techniques distribute signal power over a large range of frequencies. The receiver performs the inverse operation to represent original narrowband signal intelligibly. Spread spectrum is the lowest interference level with respect to other modulation techniques and adding more security than others since the classical receivers do not detect full signal. Three different spread-spectrum techniques are used in IEEE 802.11: Frequency hopping (FH or FHSS), Direct sequence (DS or DSSS), and Orthogonal Frequency Division Multiplexing (OFDM). FHSS passes over one frequency to another randomly and transmits a short bust each sub channel, which is the cheapest technique to realize the radio-based physical layer. DSSS uses coding functions to spread the power to larger frequency band. DSSS attains higher data rates than FHSS but it needs more sophisticated signal processing techniques. OFDM uses various parallel sub channels to send the signal like the Discrete Multi-Tone technique in DSL modems [64].

6.6 RF and IEEE 802.11

6.6.1 IEEE 802.11 RF Components

Antennas and Amplifiers are common RF components of IEEE 802.11. Antennas are vital part of the RF system since they convert electrical signals on wires into radio waves and vice versa. Amplifiers are the complementary part of antennas by permitting to transmit more power.

6.6.2 RF Propagation Problems in IEEE 802.11

In wireless networks, designer must solve following problems to maintain efficient communication: Multipath interference, and Inter-symbol interference (ISI).

Multipath Fading

One of the vital problems of wireless networks is multipath fading. The received wave is the sum of different wave components and it is impossible to separate the received signal to its components as seen in Figure 6.7.

In Figure 6.7A, the two waves are nearly replica of each other, then, the resulting received signal is approximately zero. Actually, this simulation occurs many cases. Usually IEEE 802.11 components contain omnidirectional antenna, therefore waves are reflected from different objects and the receiver collects all reflected waves as shown in Figure 6.8. First wave is the non-reflected and second and the third are reflected from different objects. The sum of three waves is nearly nothing and the receiver decides that no signal was transmitted as shown in Figure 6.7A. This is called multipath fading.

Inter-symbol interference (ISI)

Since each received signal travels different paths their phases and amplitudes will be different. Namely, if the receiver applies superposition, the obtained signal is mixed and the difference between the arrival of first signal and the last one that is called echo is delay spread. In IEEE 802.11 networks works well up to 500 ns delay spread. If the delay spread to far from desired delay spread the supported date rate will be decreased as seen in Figure 6.9.

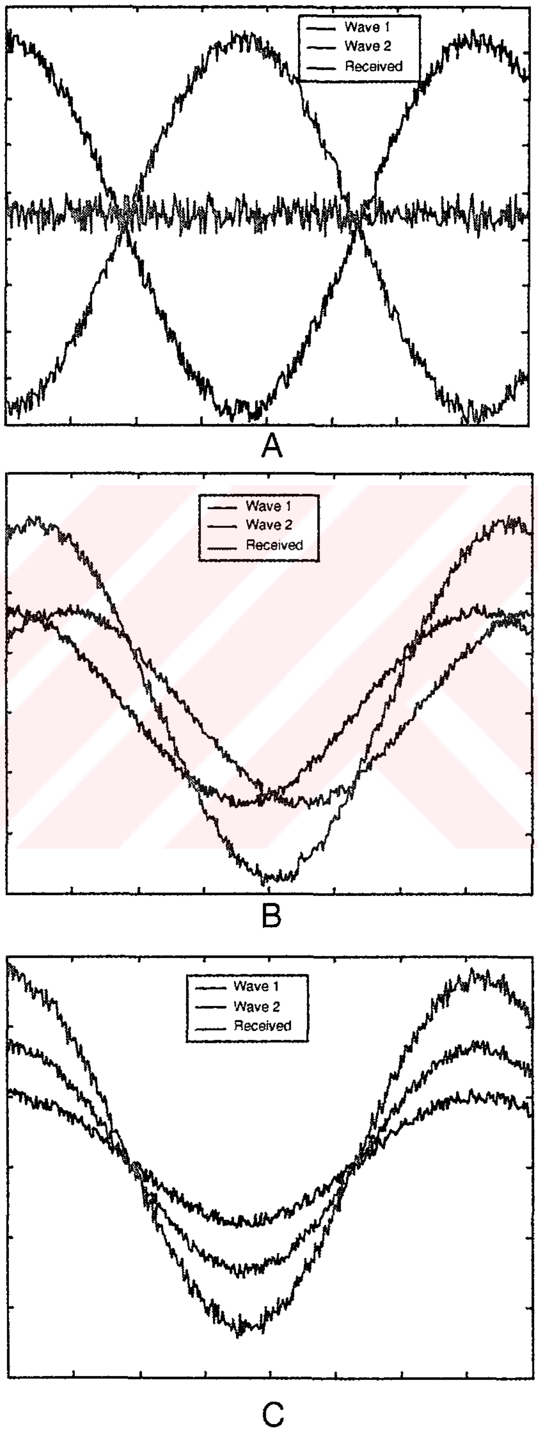

Figure 6.7: Wave combination by superposition

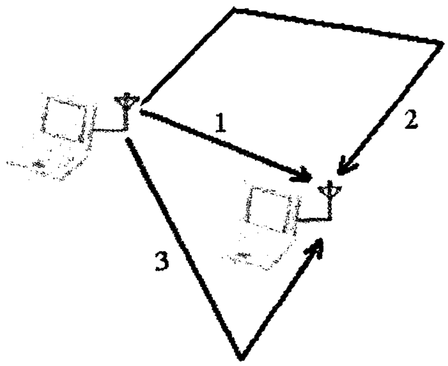

Figure 6.8: Multiple paths in transmission medium

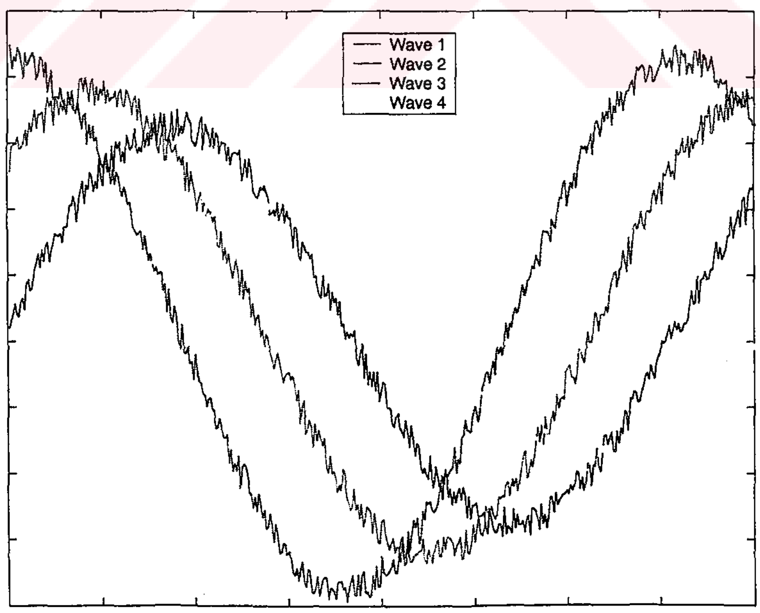

Figure 6.9: Inter-symbol interference

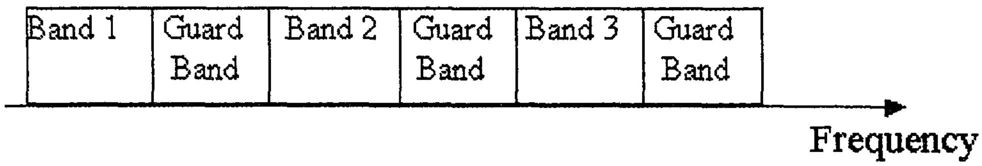

Figure 6.10: Traditional FDM

6.7 OFDM

IEEE 802.11a uses *Orthogonal Frequency Division Multiplexing* (OFDM). OFDM was invented in the late 1960s. At that time, signal processing was not that developed to realize OFDM for practical purposes. Today's challenging technologies like CDMA copes with much more mathematics than OFDM since OFDM uses single transmission into multiple subcarriers. The developments of OFDM can be found from [79] to [84]. OFDM simply divides channel into subchannels and each subchannel transmits data. To eliminate the channel frequency differences, slow channels are multiplexed into one fast channel.

6.7.1 Carrier Multiplexing

When one link is not enough for desired data rate, OFDM may combine in parallel several links such as *Frequency Division Multiplexing* (FDM). OFDM hikes up the system throughput by using various subcarriers in parallel [85, 86, 87]. In classical FDM, each user has a channel and a guard bands as seen in Figure 6.10. By using this guard band, inter symbol interference (ISI) is eliminated but system throughput is decreases sharply, so OFDM uses overlapping channels that do not interfere with each other that is called orthogonality. The meaning of orthogonality is that other subcarriers do not contribute to the over signal waveform as seen in Figure 6.11 [85, 88, 89].

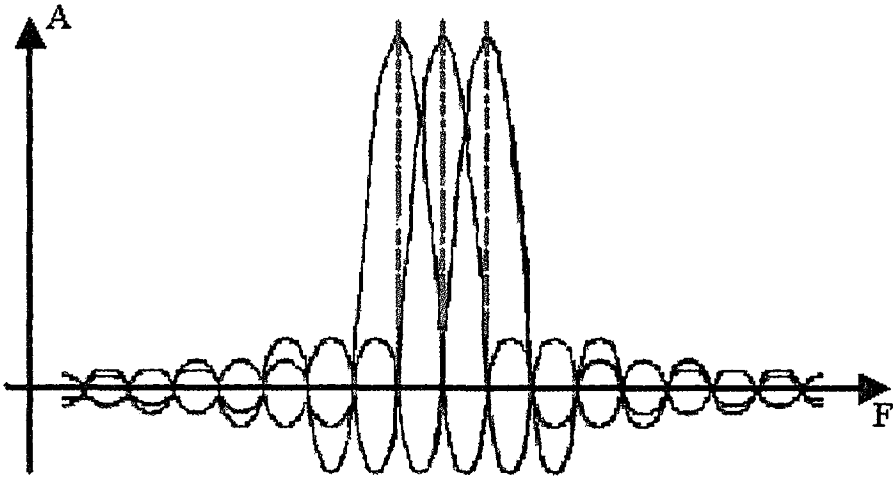

Figure 6.11: Orthogonality in the frequency domain

When transmitting signal, OFDM uses the inverse fast Fourier transform (IFFT), on the contrary, when receiving signal, OFDM takes the fast Fourier transform (FFT) to draw out each subcarrier's amplitude [85, 88, 90, 91].

6.7.2 Guard Time

On the section 6.6.2, ISI is the major problem of the receiver. However, OFDM does not deal with interference since the fast Fourier transform helps OFDM to purify unwanted late arriving components. Above all advantages, OFDM has additional drawbacks. All frequencies within a small package may give rise to interference between subcarriers. This situation stems from not only Doppler Effect but also flimsy difference between transmitter and receiver clock is called *inter-carrier interference* (ICI). To overwhelm ISI and ICI, OFDM receivers use guard time and FFT applies only non-guard time period. Delay spreads are smaller than the guard time, thus ICI does not exist but if the guard time increases so much, the system throughput decreases.

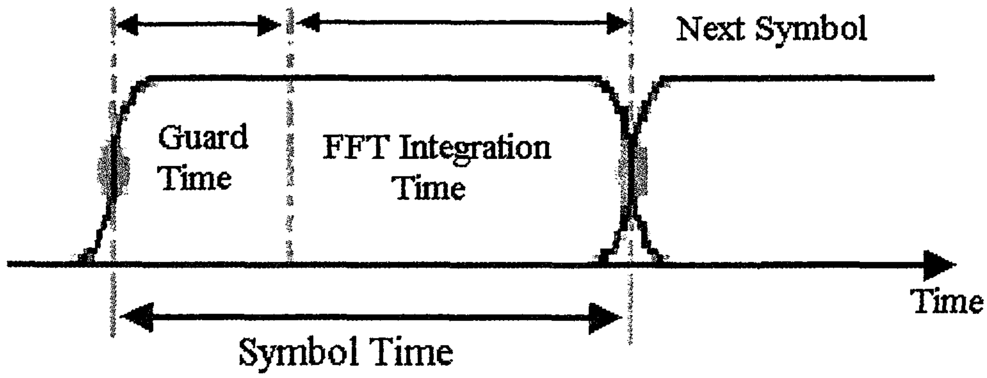

Figure 6.12: Windowing technique

6.7.3 Convolution Coding

Real proposal of the OFDM does not contain convolutional coding just some applications are confronted with deep fading the data rate downs to zero because of the small signal amplitude. The OFDM applications usually employ error correction codes like convolutional codes. In the literature, OFDM accompanies error correction codes is called COFDM. IEEE 802.11a works convolutional codes with a rate of 1/2, 2/3, and 3/4 [93].

6.7.4 Windowing

OFDM transmitters add padding bits which are called training sequences that permit smoother signal transitions from low to high power, so high frequency components are eliminated as seen in Figure 6.12[93].

6.7.5 OFDM System Parameters for IEEE 802.11a

System is determined by three parameters: bandwidth, delay, and data rate. First, the bandwidth is determined by international organizations like FCC. Second, the

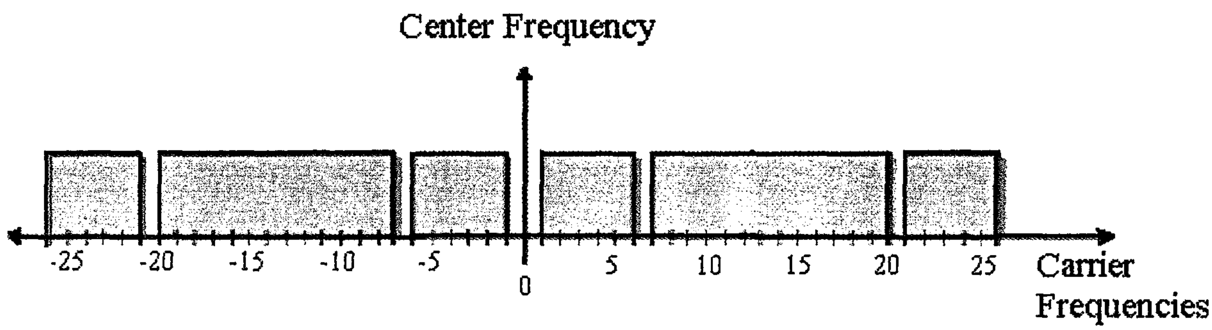

Figure 6.13: OFDM Channel Structure

delay depends on the environment where the IEEE 802.11a works, and the third, the data rate is the maximal attainable value adjusted according to other parameters.

Usually delay spreads are small but in some cases it closes to 200ns, therefore, the 800 ns is a good choice for the guard time. The applicable symbol time is at least five times more than guard time, then, the design criteria for IEEE 802.11a is the 800 ns guard time and 4 μs symbol time, and 20 MHz bandwidth. This bandwidth gives to designer system throughput range from 6 MHz to 54 MHz with altering modulation and coding [92].

Each 20 MHZ channel contains 4 channels in U-NII bands and 52 subcarriers are numerated from -26 to 26. Channels -21, -7, 7, and 21 is used for pilot carriers to control path shifts and ICI, and 48 of them are used for data transmission [93]. Channel 0 is not used due to signal processing problems as seen in Figure 6.13.

The advised channel usage is shown in Table 6.2 [94]. By using a transmit mask, one can prevent power leakage to the side bands. The transmit mask is depicted in Figure 6.14.

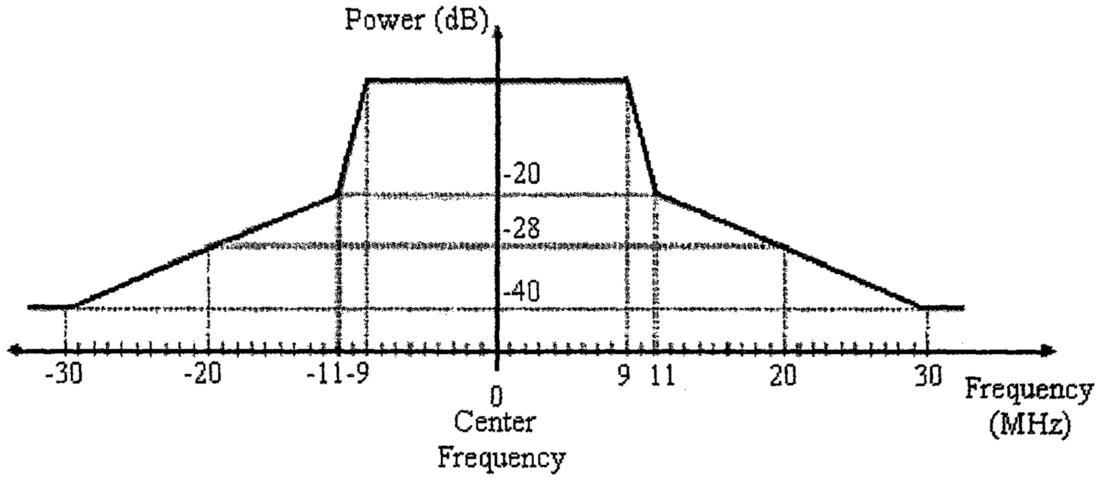

Figure 6.14: IEEE 802.11a Transmit Spectrum Mask

Band	Channel Numbers	Frequency (MHz)	Maximum output power (up to 6 dBi antenna gain)
U-NII lower band 5.15-5.25 GHz	36	5180	40mW (2.5mW/MHz)
	40	5200	
	44	5220	
	48	5240	
U-NII mid-band 5.25-5.35 GHz	52	5260	200mW (12.5mW/MHz)
	56	5280	
	60	5300	
	64	5320	
U-NII upper band 5.725-5.825 GHz	149	5745	800mW (50mW/MHz)
	153	5765	
	157	5785	
	161	5805	

Table 6.2: OFDM Operating Bands and Channels

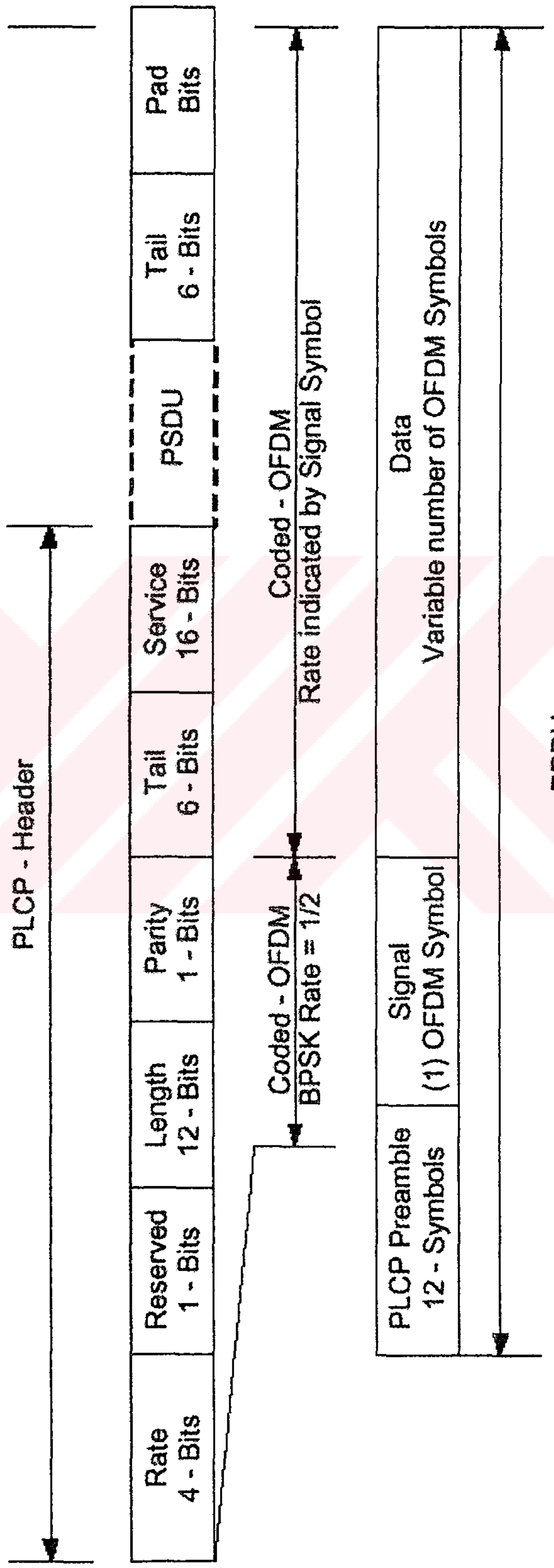

Figure 6.15: OFDM PLCP Structure

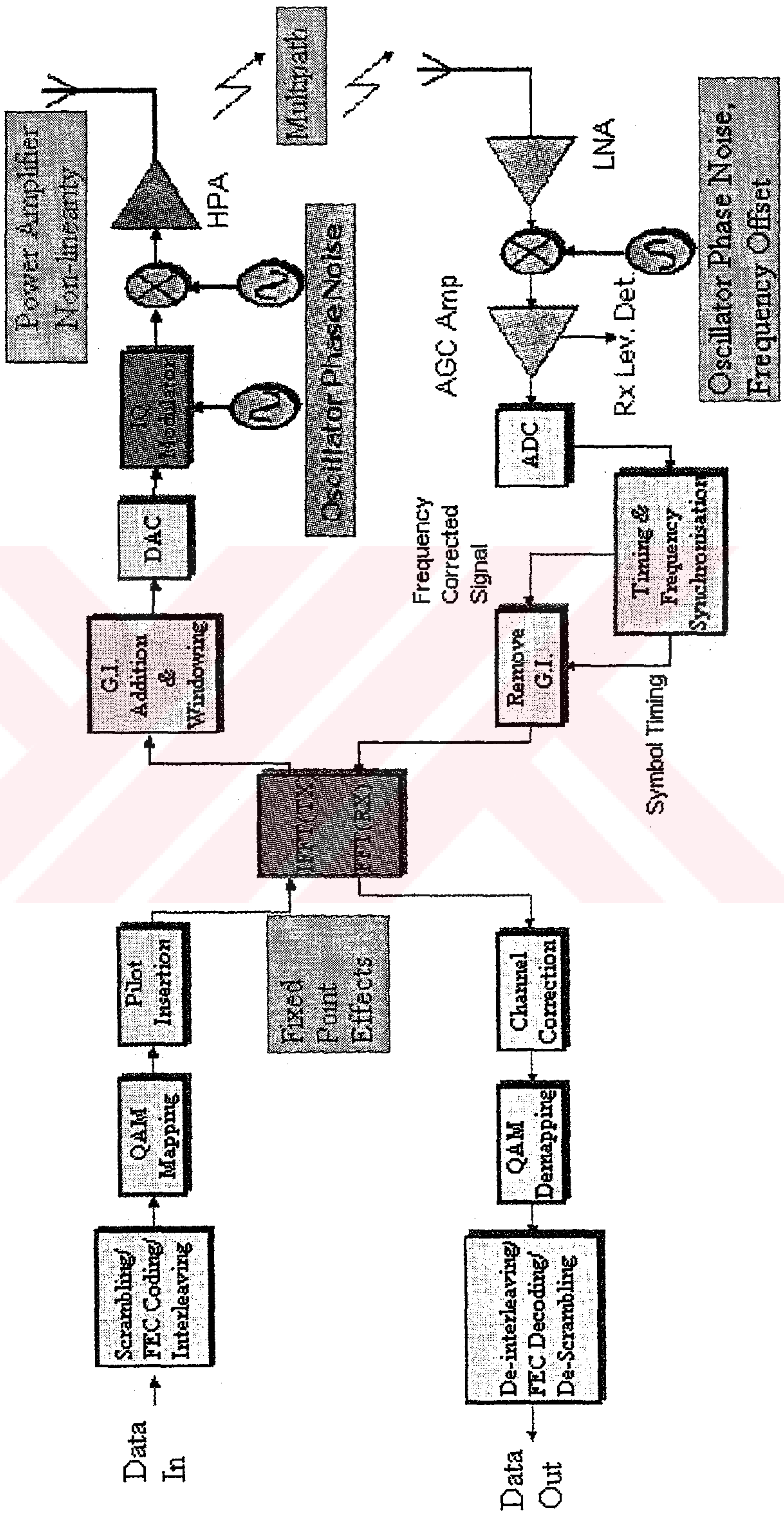

Figure 6.16: OFDM Transceiver Block Diagram [92]

6.7.6 OFDM Physical Layer Convergence Procedure (PLCP) Sublayer

The PLCP protocol data unit (PPDU) includes the OFDM PLCP preamble, OFDM PLCP header, PSDU, tail bits, and pad bits as seen in Figure 6.15. The LENGTH, RATE, a reserved bit, an even parity bit, and the SERVICE field are present in the PLCP header. The LENGTH, RATE, reserved bit, and parity bit (with 6 zero tail bits appended) are always transmitted at 6 Mbps, binary phase shift keying (BPSK) - OFDM modulated using convolutional encoding rate R=1/2. The PLCP preamble contains 10 short that are utilized for estimation of the carrier frequency and the channel and 2 long symbols that are used for calibration of frequency and channel estimates [66].

Rate Dependent Parameters

The OFDM PHY utilizes different modulation schemes to support various data rates ranging from 6 Mbps to 54 Mbps. Whatever the modulation scheme is, the physical layer uses a symbol rate of 250,000 symbols per second across 48 subchannels. Every IEEE 802.11a network must support from 6, 12, and 24 Mbps. Table 6.3 shows rate dependent parameters [92].

Timing Related Parameters

Table 6.4 depicts timing related parameters.

6.8 Completed IEEE 802.11 Standards

Besides the 802.11a and 802.11b, 802.11 standards are being progressed to meliorate security, append quality of service characteristic or broaden physical layer alternatives.

Data Rate (Mbits/s)	Modulation	Coding Rate (R)	Coded Bits per subcarrier	Coded bits per OFDM symbol	Data Bits per OFDM symbol
6	BPSK	1/2	1	48	24
9	BPSK	3/4	1	48	36
12	QPSK	1/2	2	96	48
18	QPSK	3/4	2	96	72
24	16-QAM	1/2	4	192	96
36	16-QAM	3/4	4	192	144
48	64-QAM	2/3	6	288	192
54	64-QAM	3/4	6	288	216

Table 6.3: Rate dependent parameters

Parameter	**Value**
N_{SD} : Number of data subcarriers	48
N_{SP} : Number of pilot subcarriers	4
N_{ST} : Number of subcarriers, total	$52(N_{SD}+N_{SP})$
Δ_F : Subcarrier frequency spacing	0.3125 MHz (=20 MHz/64)
T_{FFT} : IFFT/FFT period	3.2 μs $(1/\Delta_F)$
$T_{PREAMBLE}$: PLCP preamble duration	16 μs $(T_{SHORT} + T_{LONG})$
T_{SIGNAL} : Duration of the SIGNAL BPSK-OFDM symbol	4.0 μs $(T_{GI} + T_{FFT})$
T_{GI} : GI duration	0.8 μs $(T_{FFT}/4)$
T_{GI2} : Training symbol GI duration	1.6 μs $(T_{FFT}/2)$
T_{SYM} : Symbol interval	4.0 μs $(T_{GI} + T_{FFT})$
T_{SHORT} : Short training sequence duration	8 μs $(10*T_{FFT}/4)$
T_{LONG} : Long training sequence duration	8 μs $(T_{GI2}+2*T_{FFT})$

Table 6.4: Timing related parameters

The IEEE tries to finalize following standards. The *IEEE 802.11a* is a 5GHz physical layer standard for wireless local area networks which was completed in 1999 [66]. The IEEE 802.11a uses different modulation schemes to support several data rates ranging from 6 Mbps to 54 Mbps. Advantages of IEEE 802.11a are higher data rate and better interference isolation against neighboring access points. The *IEEE 802.11b* is a 2.4 GHz physical layer standard for wireless local area networks which was completed in 1999 [67]. Since 2001, IEEE 802.11b products have been available in the market. Maximum available data rate 11 Mbps. Important drawbacks of the IEEE 802.11b are lower data rate for future network design and high interference from neighboring access points. The *IEEE 802.11c* is to provided documentation of 802.11-specific MAC procedures to the ISO/IEC (International Organization for Standardization/International Electrotechnical Commission)[95]. The *IEEE 802.11d* clarifies definitions, requirements, and restrictions to allow the IEEE 802.11 standard to operate in countries where the 802.11 standards cannot legally work [95] [96].

6.9 Conclusion

Wireless local area networks are the cheap and superior solution for providing next generation wireless services to indoor and campus hot spots. Namely, mixed networks help address the growing demand on uninterrupted high-speed data access by utilizing both 3G wide-area mobile networks, which offer ubiquitous geographic coverage, and WLANs, which offer high speeds but more limited coverage. Above statement explicates that why funding, coverage, and roaming are big challenges facing up WLAN operators. So, this chapter provides a background for producing heterogeneous networks via rendering general overview of WLANs and its standards, design challenges, network architectures, physical and MAC layer of IEEE 802.11, OFDM structure used by IEEE 802.11a, which is the ultimate goal of this thesis.

Chapter 7

MIGRATION ISSUES FROM 3G TO 4G

Present 3G carrier technologies cannot separately cover all the demands of the end-user in terms of coverage, bandwidth, quality of service (QoS) and cost. For instance, IS-856 networks supports only up to 1 Mbps wireless packet data, IEEE 802.11a transmits up to 54 Mbps at relatively low deployment cost but low user density and coverage range are the crucial problems. The 4G networks are heterogeneous networks that eliminate previous technologies' drawbacks and contain large number of different access methods. Therefore, new access methods are needed to combine some of the existing network topologies is called *joint service* that provides wireless data connectivity for nomadic users when away from their offices and homes.

In the literature different hybrid topologies proposed. In [97, 98], a possible architecture is proposed for integrating UMTS and 802.11 WLAN. This structure permits a mobile node to support data connection through WLAN and voice connection through UMTS in parallel. In [99], the author explains the IS-856 cellular data (1xEV) can be married with IEEE 802.11b wireless data to maintain wide area Internet access for service providers and users. In [100], an interworking mechanism is proposed, which combines WLANs and cellular data networks into integrated wireless data environments capable of ubiquitous data services (GPRS) and provide very high data rates in hot spot locations. The difference between previous suggestions and this thesis is that the proposed configuration supports data rate. Since the IS-856 and IEEE 802.11a are the highest data rate systems. The overall throughput is much higher than the previously offered systems' throughput.

This chapter explains the infrastructureless elements necessary to enable joint service using IEEE 802.11a-based wireless local area networks (WLAN), which can be integrated with a IS-856 or 3G network and how profitable, consumer-friendly public

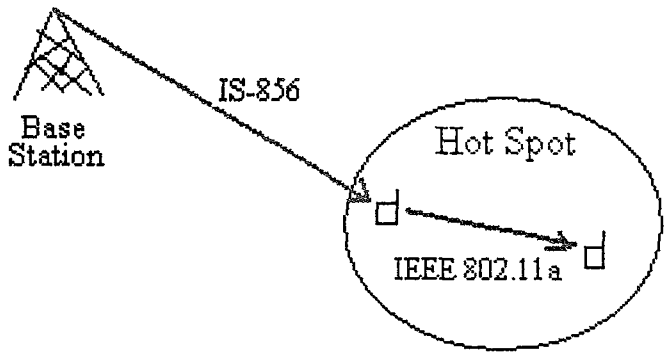

Figure 7.1: Heterogeneous Network Structure

"hot spot" networks can be created using this type of heterogeneous networks, and proposes new type scheduling and routing algorithms, and tries to solve fairness power consumption problem in heterogeneous networks. The integration of heterogeneous networks helps to increase data rates of IS-856 more than 50% as seen in Figure 7.1.

Second, a joint service that allows the integration of available IS-856 and IEEE 802.11a networks into a single platform capable of supporting user roaming between them, while not interrupting active communications, will gain importance. This improvement will be aided by the boost of new mobile devices capable of receiving and transmitting two different frequencies: 2 GHz and 5 GHz [103].

Finally, the most important contribution of this thesis, *New Access System*, will be explained in this chapter which increases system throughput approximately 50% and decreases latency figures around 50%.

7.1 Routing & Scheduling Algorithms for Heterogeneous Networks

Peradventure, the most important part of the heterogeneous networks is applied routing and scheduling algorithm. As explained in the chapter 3, the selection of the scheduling algorithm affects the IS-856 system throughput and the average delay of the users. In addition to IS-856 system, network engineer should consider the IEEE 802.11a network requirements like power consumption. Different power efficient Ad Hoc routing protocols that helps to keep up network lifetime for ad hoc type IEEE 802.11a networks, have seemed in the literature. The famous ones are Minimum Total Transmission Power Routing (MTPR)[102], Minimum Battery Cost Routing (MBCR)[101], Min-Max Battery Cost Routing (MMBCR)[101], and Max-Min battery Capacity Routing [106]. But, the heterogeneous network structure reveals a fair power consumption problem in heterogeneous networks that is not covered yet. For this reason, the thesis deals with fairness issue rather than power efficient routing algorithms.

The previous cellular topology as shown in Figure 4.1 is applied, 2-tier 19-cell environment, just adding Hot Spot with different locations. The Hot Spot is located at 50 m, 500 m, 750 m, and 950 m, respectively. The concerned cell is surrounded by the first layer has 6 and the second layer has 12 cells. The radius of each cell is 1 km in the layout and the radius of each Hot Spot is 50 m in the cell. We accepted that 50% of the 4000 users are distributed uniformly over the 19-cell and the rest of the users are dropped uniformly over the Hot Spot. The positions of the Hot Spot and user distributions are shown in Figure 7.12-7.15. Simulations assume that IEEE 802.11a network is taken under ideal conditions. Namely, Hot-Spot service is always available.

The aim is to calculate a cumulative distribution function for the carrier to interference (C/I) ratio of the Hot Spot for each different position since cellular user distribution is already experienced in chapter 4. Erstwhile 2000 users are dropped into the Hot Spot, the carrier to interference ratio is forecasted for each user on an individual basis allow path loss, shadow fading, Rayleigh fading and the number of multipaths are present in the wireless surrounding. On the calculation of (C/I), all base stations transmit at full power and mobility of users have not been considered.

Hot Spot Mobility Model

As submitted chapter 4, the Jakes model is a nice solution for representing the channel characteristics of different mobile speed.

$$R_c(\tau) = J_o(2\pi f_d \tau) \tag{7.1}$$

The Doppler frequency in the Hot Spot, f_d taken in this thesis is 0.925925 Hz that matches to mobile speed 0.5 km/h and the Doppler frequencies in the cellular region regarded are 5.56 Hz, 55.56 Hz and 185.185 Hz represent mobile speeds of 3 km/h, 30 km/h, and 100 km/h, respectively, as in the chapter 4. The experienced (C/I) values are obtained in the Hot Spot as seen in Figure 7.16-7.19. The mobility will be integrated later on with using Finite Impulse Response (FIR) filter to get Jake′s spectrum. The Parks-McClellan optimal equiripple FIR filter have been configured for the mobile speed 0.5 km/h with 925 taps. Once the C/I values are obtained according to cdf of Figure 7.16-7.19, obtained numbers are infiltrated the representing FIR filters for appropriate mobility model.

7.1.1 Fair Power Consumption Problem in Heterogeneous Networks

In wireless medium, transmitted signals are attenuated with distance exponentially, namely, as the distance increases the supported data rate decreases. In heterogeneous network structure, some of the users are close to the base station and their data rates are usually higher than the other users' data rates, hence, if no precaution is taken inside the Hot Spot, every transmission will be accomplished by near user battery which can be run out in a short time. To puzzle out this crucial problem, the thesis proposed that utility factor, ζ, is added to Proportional Fair and Modified Exponential-1 algorithms. The names of new algorithms are called Proportional Fair Scheduler-Hot Spot (PF-Hot Spot) and Modified Exponential-1-Hot Spot (Mod.Exp.-Hot Spot) that ensure every WLAN user receive data from other Hot Spot users at any rate half of the transmitted times. Mathematically, utility factor can be calculated

$$\zeta_i = \frac{\text{The number of times received}}{\text{The number of times sent}} \tag{7.2}$$

where i is the user number inside the Hot-Spot.

7.1.2 Utility Factor Selection

In subsection 7.1.1, the power consumption problem in heterogeneous networks can be solved by adding utility factor into the algorithm. However, the selection of utility factor is a crucial issue both to minimize battery consumption and to support fairness. The cellular Ad-Hoc hybrid system was affirmed to have good performance from the point of battery consumption [104] but due to cellular network feedback, keeping the wireless equipments always on grows the consumed power a little bit [105]. However, [105] illustrates that the highest power consumption is achieved when the downlink or uplink data transmission occurs. So, utility factor threshold depends on following three parameters:

1. Minimum number of transmission
2. Maximum Throughput increase
3. To decrease users utility factor standard deviation

Under the above parameters, the proper utility factor is determined with detailed simulations. Simulation environment consists of two different of user groups. First one is utilized both IEEE 802.11a and IS-856 network and their speed is 0.5 km/hr. The Hot Spot position is shown in Figure 7.13. The second group is utilized only IS-856 network and their speeds are 100 km/hr.

From Figures 7.2-7.11, the utility factor does not affect the latency performance. So, the throughput is unique parameter to check utility factor selection. The 1050 kbps and 1100 kbps are taken as a reference values to check throughput performance. When the scheduler employs the Mod.Exp.-Hot Spot to obtain 1050 kbps throughput, heterogeneous system must contain 16 users, 16 users, 17 users, 17 users, and 19 users for utility factor values 0.25, 0.50, 0.60, 080, and 0.90, respectively. If the mixed system needs 1100 kbps throughput, the system must include 24 users, 24 users, 25 users, 28 users, and 29 users for the utility factor values are 0.25, 0.50, 0.60, 080, and

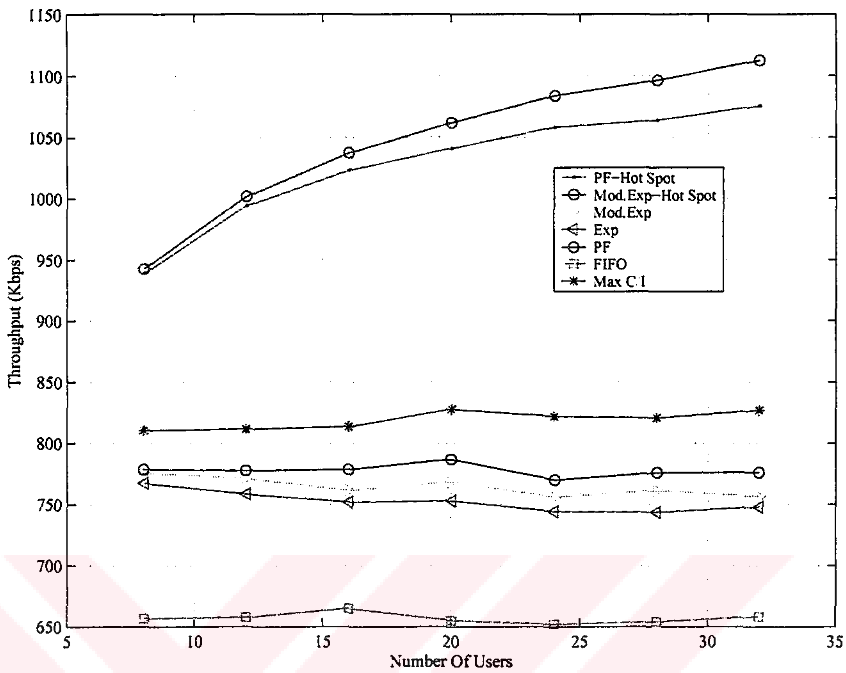

Figure 7.2: Hot Spot Position at 500 m with Utility factor 0.90 Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

0.90, severally. The same rank can be obtained if the scheduler uses the PF-Hot Spot to obtain 1050 kbps throughput, 18 users, 18 users, 18 users, 22 users, and 23 users for the utility factor values are 0.25, 0.50, 0.60, 080, and 0.90, respectively.

The best utility factor supports highest throughput with a minimum number of users. Therefore, the utility factor values are 0.25 and 0.50 are the best utility factor constants. However, when the utility factor constant decreases some of the users transmit or receive higher than the others and their batteries can be run out fast. Consequently, the constant, 0.50, is selected threshold utility factor value for further simulations.

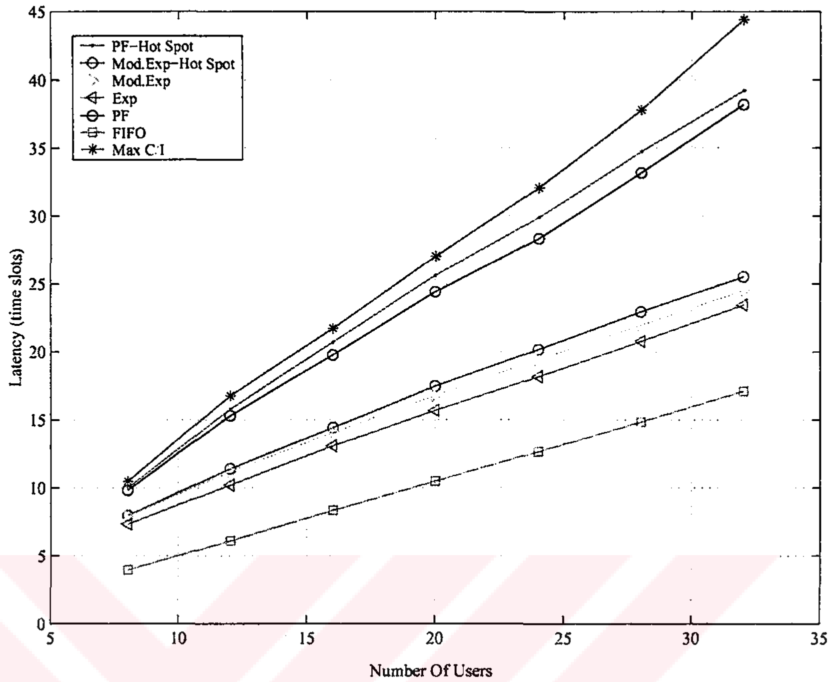

Figure 7.3: Hot Spot Position at 500 m with Utility factor 0.90 Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

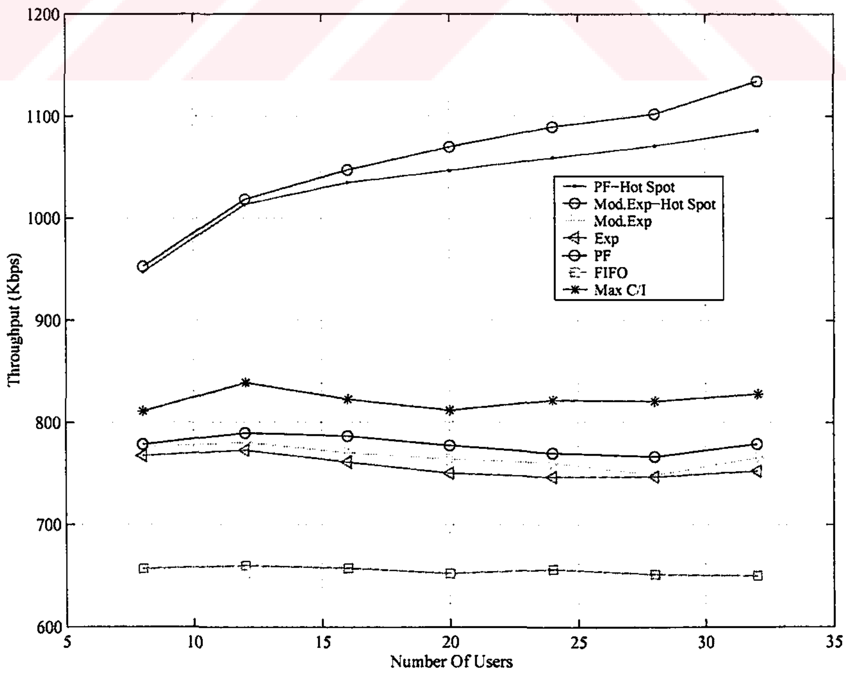

Figure 7.4: Hot Spot Position at 500 m with Utility factor 0.80 Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

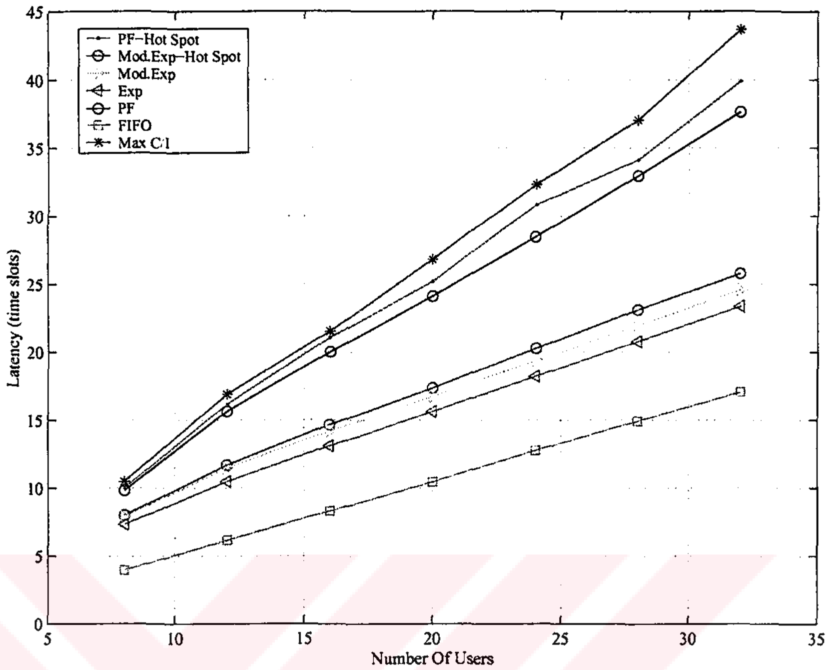

Figure 7.5: Hot Spot Position at 500 m with Utility factor 0.80 Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

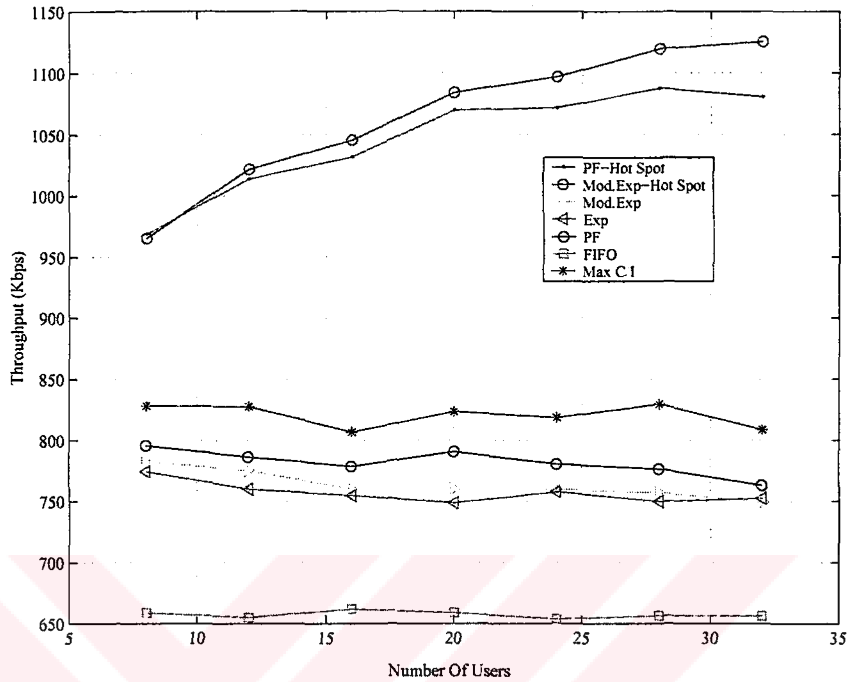

Figure 7.6: Hot Spot Position at 500 m with Utility factor 0.60 Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

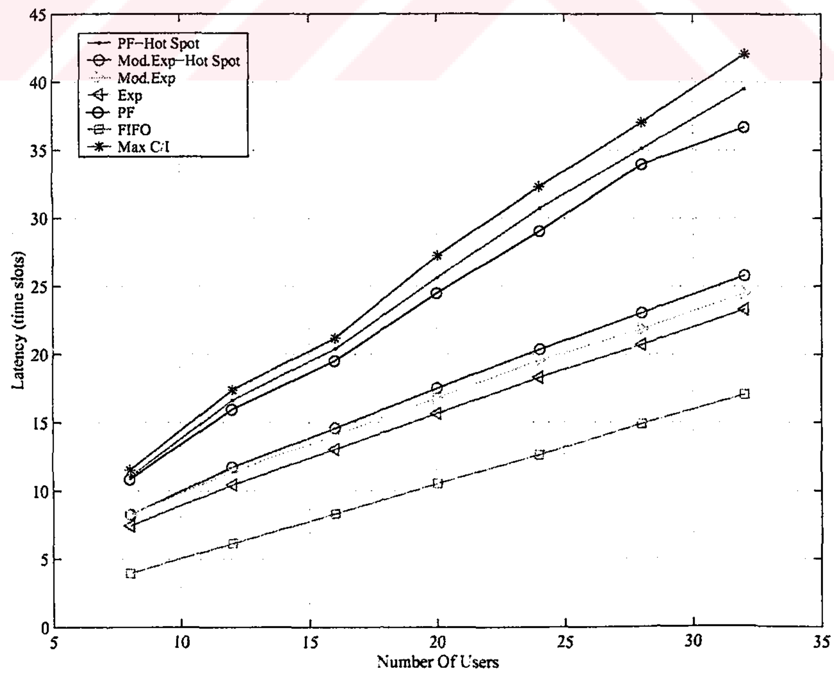

Figure 7.7: Hot Spot Position at 500 m with Utility factor 0.60 Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

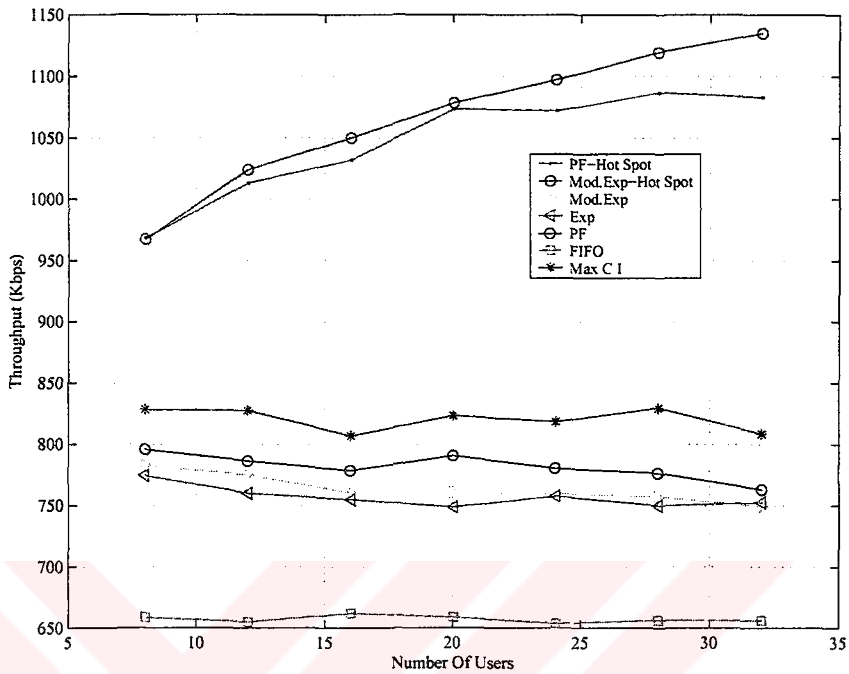

Figure 7.8: Hot Spot Position at 500 m with Utility factor 0.50 Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

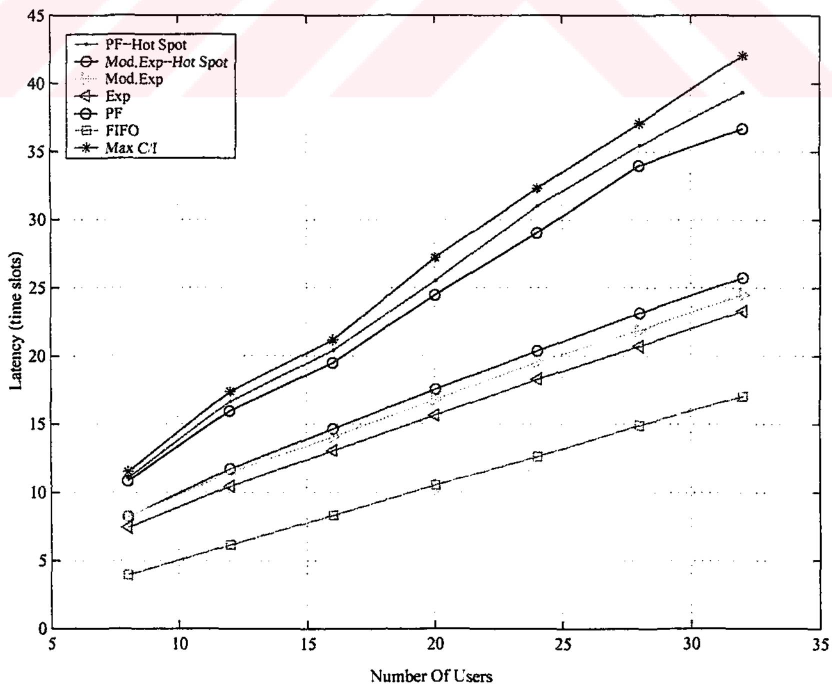

Figure 7.9: Hot Spot Position at 500 m with Utility factor 0.50 Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

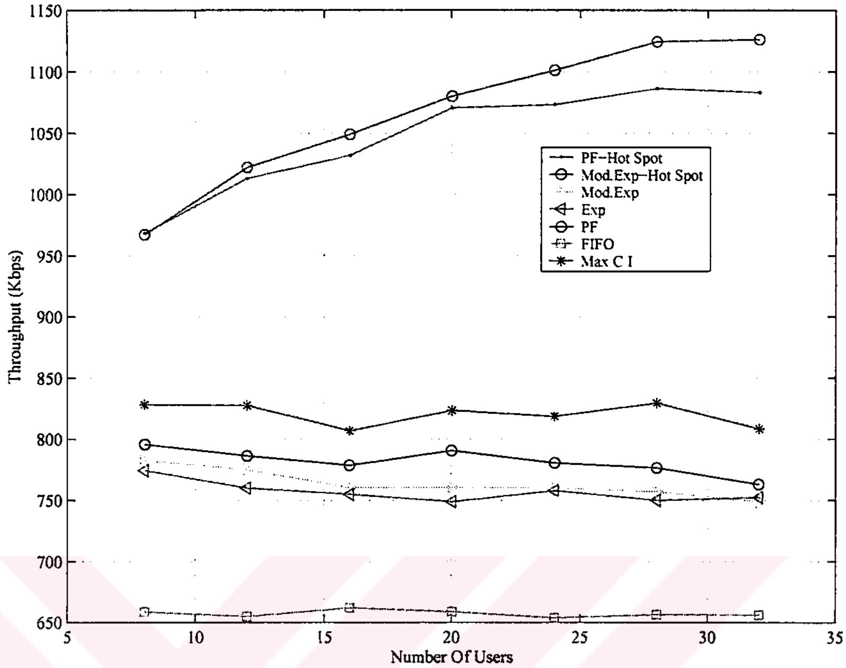

Figure 7.10: Hot Spot Position at 500 m with Utility factor 0.25 Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

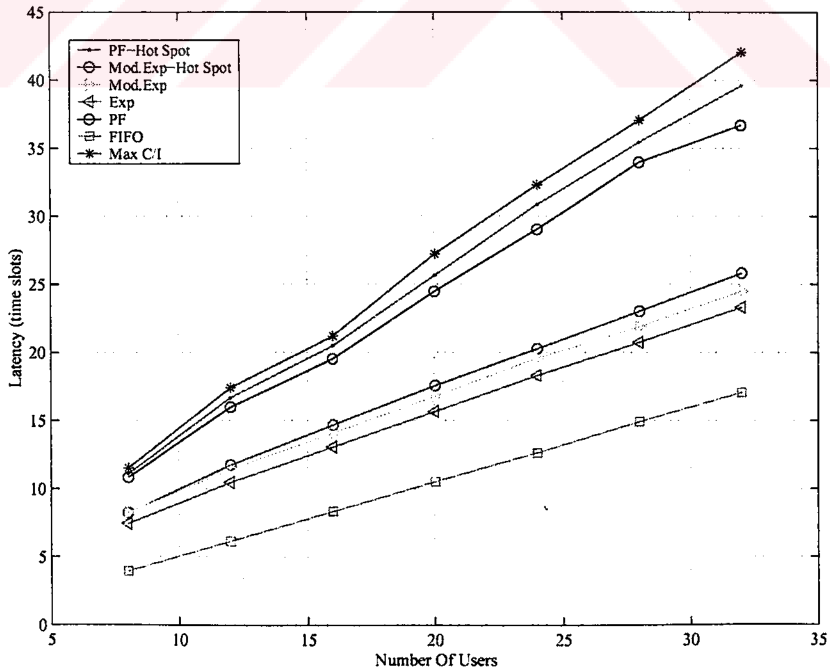

Figure 7.11: Hot Spot Position at 500 m with Utility factor 0.25 Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

7.1.3 Modified Exponential-1-Hot Spot Scheduler(Mod.Exp.-Hot Spot)

According to findings of the Modified Exponential-1 & 2 in chapter 3, the proper scheduling algorithm has two inputs: One is obtained from the time-varying channel characteristics and the other is taken from observed user latencies. Mathematically, modified exponential scheduler schedules user

$$j = \arg\max_i \; (a_i \frac{r_i(kt_s)}{\overline{r_i(kt_s)}})^2 \; exp(\frac{a_i li(kt_s) - \overline{al(kt_s)}}{1 + \sqrt{\overline{al(kt_s)}}}) \tag{7.3}$$

at time slot k.

When the one of the WLAN user is selected from scheduler, the combined algorithm checks maximum data rate inside the Hot Spot, then, scheduler controls utility factor, ς , is the ratio between the number of times data received by mobile station and the number of times data sent. In three cases base station transmits data to the scheduler selected user directly, strictly speaking, IS-856 system does not take advantage of Hot Spot opportunities:

1. Higher Data Rate users in the Hot Spot do not satisfy utility factor
2. Scheduler selected user is the highest data rate user in the Hot Spot
3. Scheduler selected user is outside the Hot Spot

If above three condition is not satisfied, namely, scheduled user is in the Hot Spot, and at least one user's data rate is higher than scheduled user's data rate and his/her utility factor is greater or equal to 0.5, then, the base station sends data to the higher data rate user with his/her data rate by the way of IS-856 network. After data is received by highest data rate user, this user transmits data to the scheduled user via IEEE 802.11a network and increments the number of times data sent. Whenever scheduled user gets the transmitted data, scheduler adds the number of times data received by mobile station.

7.1.4 Proportional Fair-Hot Spot Scheduler(PF-Hot Spot)

The proportional fair algorithm is the common scheduling algorithm to analyze the IS-856 system performance. The Hot Spot application of Proportional Fair algorithm

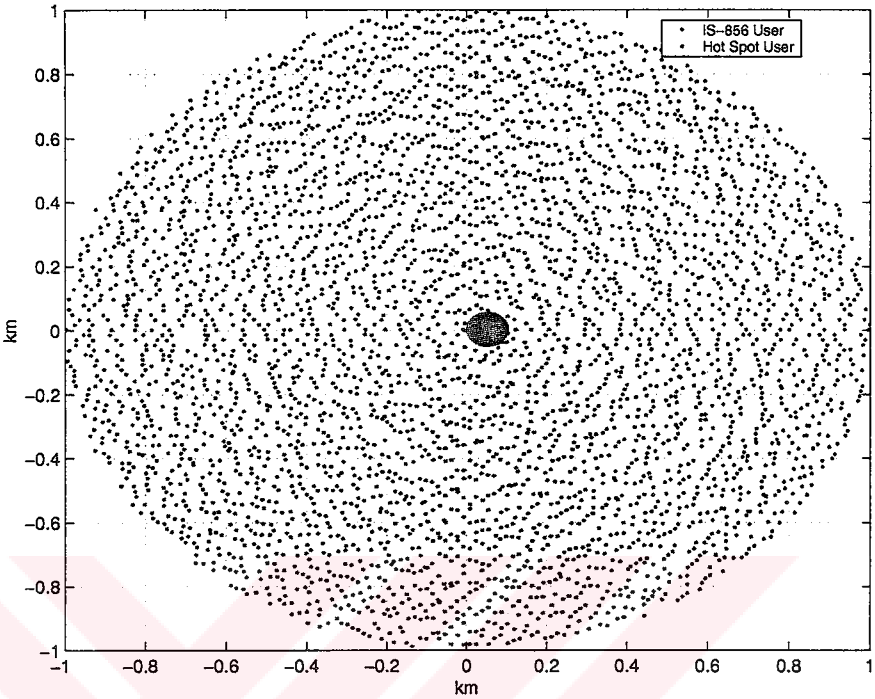

Figure 7.12: User distribution where the Hot Spot at 50 m

is a good benchmark for previous algorithm, Mod.Exp.-Hot Spot. Mathematically, proportional fair schedules user

$$j = \arg\max_i \left(\frac{r_i(kt_s)}{\overline{r_i(kt_s)}}\right). \quad (7.4)$$

at time slot k. If the scheduled user in the Hot Spot, first, scheduler checks presence of higher data rate user different than the scheduled user. Second, at least one of higher data rate user′s utility factor should be greater or equal to 0.5 to give a service with IEEE 802.11a network structure. For instance, we have 3 users inside the Hot Spot and their IS-856 data rates are 76.8 kbps, 153.6 kbps, and 614.4 kbps, respectively and their utility factors are 0.7, 0.8, and 0.45, severally. If user 1 is selected by the scheduler, then, scheduler sends data to user 2 via IS-856 system with data rate 153.6 kps and user transmits data to user 1 by IEEE 802.11a network. If user 2 or 3 is chosen, scheduler sends data directly to the selected user to save energy and time.

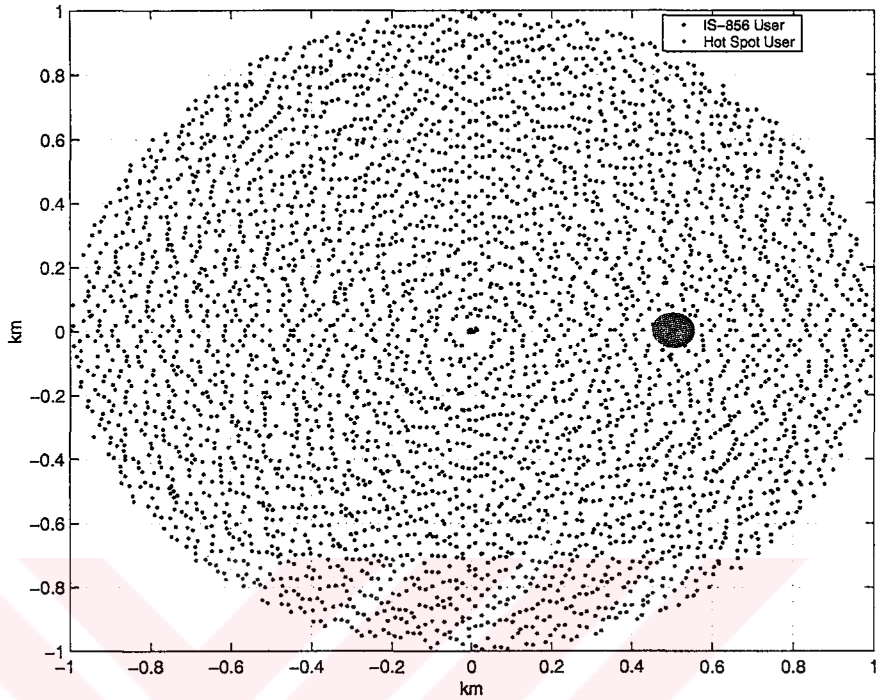

Figure 7.13: User distribution where the Hot Spot at 500 m

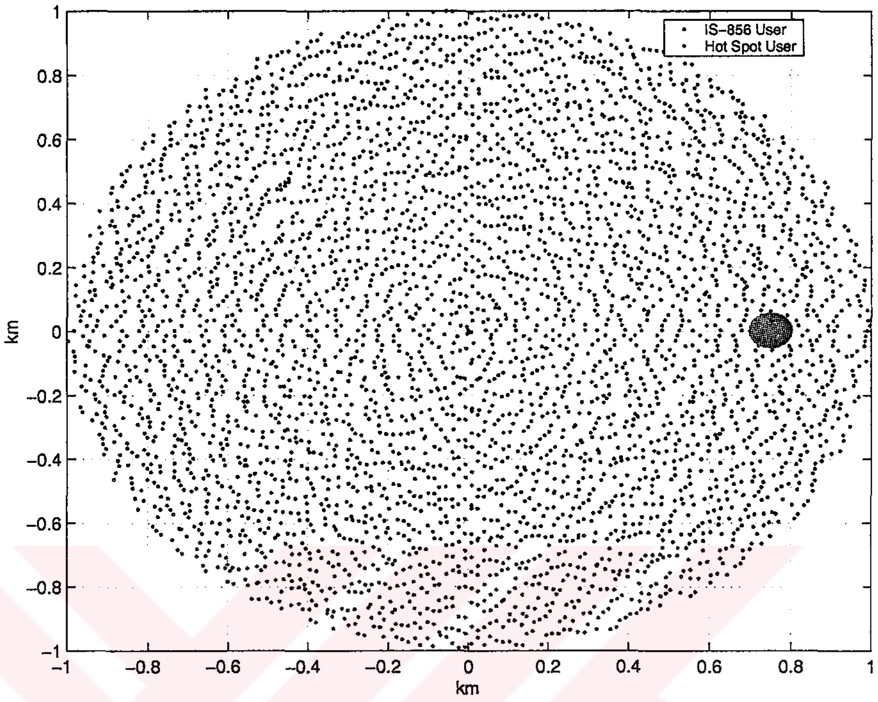

Figure 7.14: User distribution where the Hot Spot at 750 m

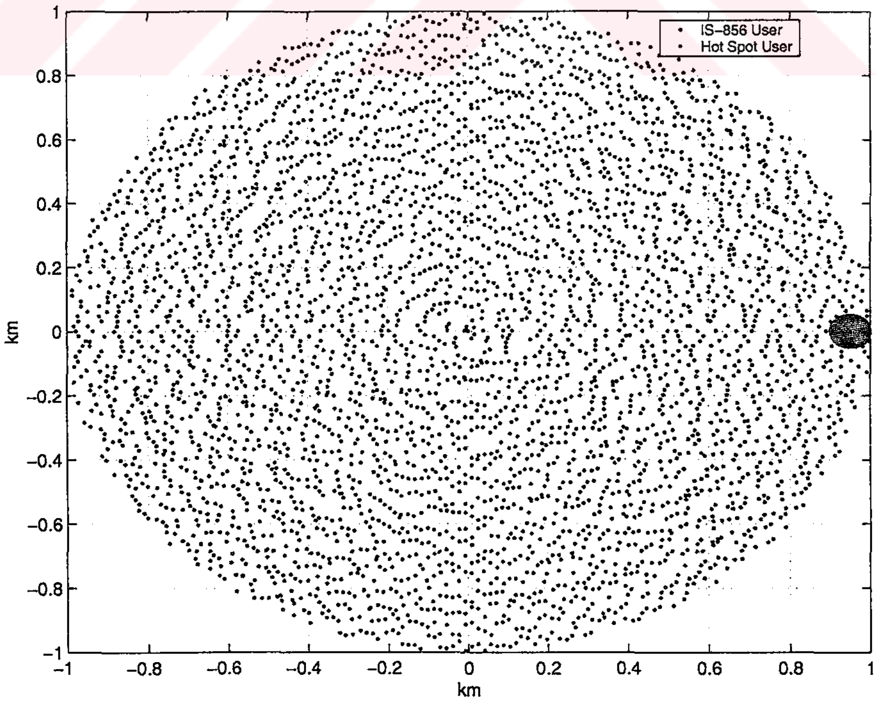

Figure 7.15: User distribution where the Hot Spot at 950 m

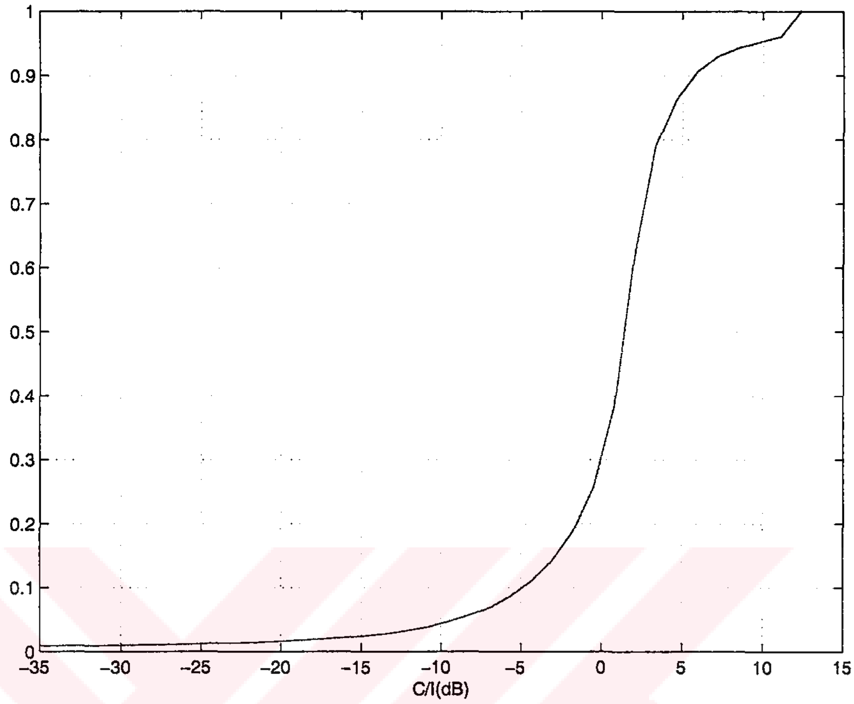

Figure 7.16: Cumulative Distribution Function of the C/I values for the Hot Spot at 50 m

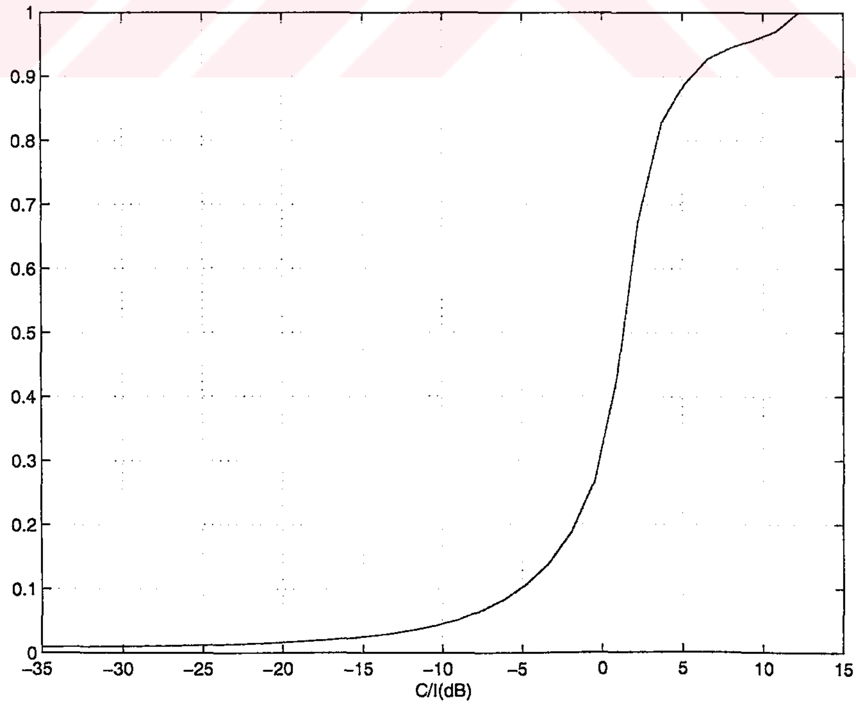

Figure 7.17: Cumulative Distribution Function of the C/I values for the Hot Spot at 500 m

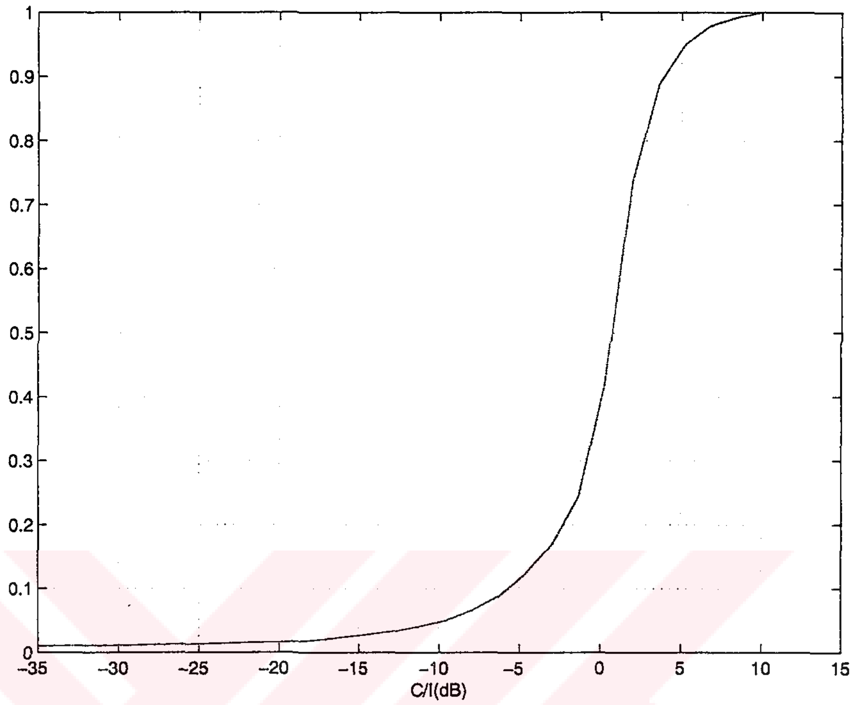

Figure 7.18: Cumulative Distribution Function of the C/I values for the Hot Spot at 750 m

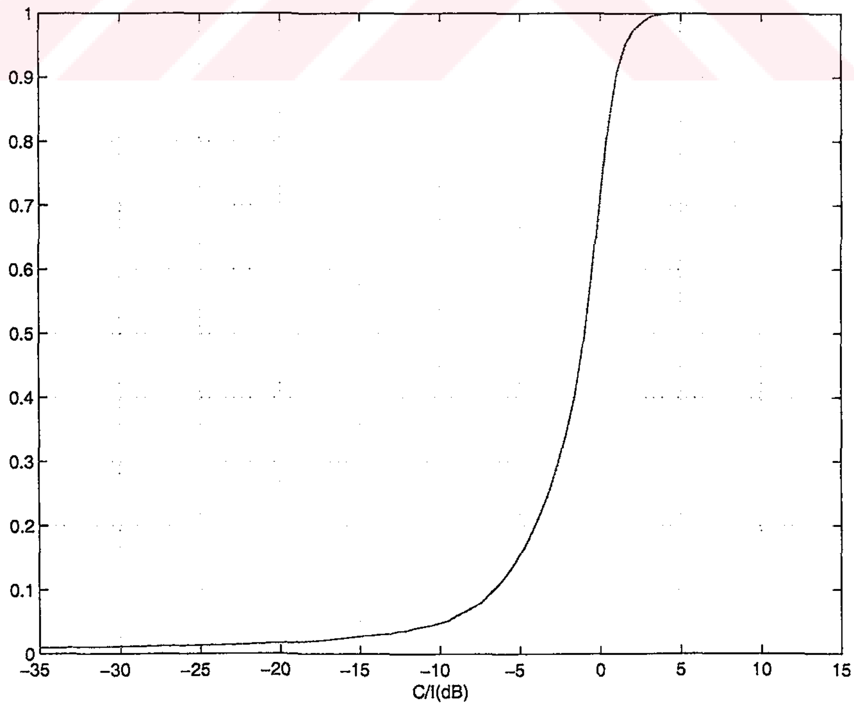

Figure 7.19: Cumulative Distribution Function of the C/I values for the Hot Spot at 950 m

7.2 Hot Spot Simulation Results

The heterogeneous network, the IS-856 and IEEE 802.11a, is studied and looked into the modification in the experienced mixed system throughput and average latency values as a function of the users present in the system. Apiece Hot Spot position, throughput and latency outcomes are held for cellular environment speeds: the 3 km/h, 30 km/h, and 100 km/h and for Hot Spot surrounding speed the 0.5 km/h.

If the channel is perfectly estimated, it is obvious that as the Doppler frequency increases the system throughput the system throughput grows and the observed latency decreases. But, the delay between the transmission format request made by the mobile user and real transmission of the packet data is 3 slots in IS-856 system. Due to this 3 slot round-trip delay, the delayed feedback information is wounded as the Doppler increases and indifferent from real channel characteristics. To obtain proper heterogeneous system simulation results, the 3 slot round-trip delay is added to the feedback data.

The scheduling algorithms under consideration in this chapter are the Modified Exponential-1, Exponential Rule, Proportional Fair, FIFO Rule, and Maximum C/I rule as the five benchmark algorithms that show system performance only IS-856 system is used, and the two new schemes, Proportional Fair-Hot Spot Scheduler and Modified Exponential-1-Hot Spot Scheduler, that are developed for check hybrid system performance. In the following subsections, mixed system performance will be examined with different Hot Spot positions.

7.2.1 Hot Spot Position at 50 m

Heterogeneous system consists of two types of user group. First one is utilized both IEEE 802.11a and IS-856 network and their speed is 0.5 km/hr. The position of the Hot Spot where the group stays during the simulation is shown in Figure 7.12. The second communal is employed only IS-856 network and their speeds are changed in three situations: the pedestrian, low mobile speed and fast vehicular speed correspond to 3 km/hr, 30 km/hr, and 100 km/hr, respectively.

¿From previous simulations and theoretical backgrounds, except FIFO scheduler all scheduling algorithms benefit from multi-user diversity in the hybrid system environment that is the why its throughput and observed latency figures are minimum and Maximum C/I rule′s throughput and latency values are the highest. Yet, the new hybrid system schedulers′ performance is superior to single IS-856 system schedulers′ performance as seen in Figures 7.20-7.25.

The comparison between PF-Hot Spot and PF algorithms when the 32 users present in the system, mixed throughput is increased from 944 kbps to 1366 kbps for 3 km/hr, from 771 kbps to 1035 kbps for 30 km/hr, and from 787 kbps to 1105 kbps for 100 km/hr although system latency figures are not changed more than 6%. Because of similar structures the Mod.Exp.-Hot Spot and Mod.Exp.-1 algorithms are matched for evaluating hybrid system versus IS-856 performance. Mixed system throughput altered from 881 kbps to 1335 kbps, 760 kbps to 1100 kbps, and 772 kbps to 1157 kbps at 3km/hr, 30 km/hr, and 100 km/hr mobile speed environment, severally. The augmentation in the latency figures is slightly larger than IS- 856 system only and can be easily neglected due to high throughput gain.

The evaluation of proposed algorithms is another important issue. The throughput of PF-Hot Spot scheme is surpassed only 3 km/hr and 0.5 km/hr hybrid system and its latency values are 13 or 14 time slots more than Mod.Exp.-Hot Spot latency figures. PF-Hot Spot scheme does not take advantage of hybrid IEEE 802.11a and IS-856 properly. This stems from utility factor, ζ, that provides a kind of fairness, limits PF-Hot Spot scheme Hot Spot throughput with giving a service with lower data rates.

7.2.2 Hot Spot Position at 500 m

The story is the same except the position of the Hot Spot which is further than previous scenario as seen in Figure 7.13. The position of the Hot Spot is not far enough from the base station to increase exposed interference from neighbor base stations as seen in Figure 7.17, for this reason, calculated signal to interference ratio is almost equal to previous scenario, that is the why, the merit of throughput and observed latency is slenderly worse than former script where Hot Spot sits 50 m apart from base station more Figure 7.26-7.31, so, early commands are still valid.

7.2.3 Hot Spot Position at 750 m

The simulation condition is constant if the distance of the Hot Spot is excluded as seen in Figure 7.14. The high signal to interference ratio is endangered by increasing distance between Hot Spot and the base station that can be seen in Figure 7.18. The rank is not changed when matching traditional five benchmark scheduling algorithms. The FIFO rule has the lowest throughput and latency, on the contrary, the Maximum C/I has the highest throughput and latency and the others are in between as shown in Figure 7.32-7.37.

The simulation results depict that heterogeneous network throughput is superior to single IS-856 system with 32 users since PF throughput is gained 47% for 3 km/hr case, 42% for 30 km/hr event, and 45% for 100 km/hr situation. In addition to PF, Mod.Exp.-1 throughput is, also, amplified more than 50% for all cases. The cost of this extreme throughput is additional latency figure in hybrid system, 1 or 2 slot(s), end to end transmission delay which is not taking into account, and extra battery usage in Hot Spot.

7.2.4 Hot Spot Position at 950 m

Except Hot Spot location, no voice is heard from simulation terms as shown in Figure 7.15. Now, the interference level is strong enough to affect system performance badly is drawn in Figure 7.19. Once more, classical benchmark algorithms are placed between FIFO and Maximum C/I with a lower throughput because of worst radio channel conditions that is demonstrated in Figure 7.38-7.43.

Results are obtained from heterogenous network throughput give us more desire than ever before to design heterogenous network. Although the Hot Spot location is not suitable for observing appropriate signal to interference ratio, the hybrid network throughput with 32 users is increased more than 55% with PF-Hot Spot scheme and 62% with Mod.Exp.-Hot Spot algorithm. The price is again a few latency figures, delay, and the battery.

7.2.5 Heterogeneous Network Earnings

The detailed simulations showed the followings:

1. The traditional IS-856 network throughput will increase roughly 50% through applying the IS-856 and IEEE 802.11a heterogeneous network structure that the utility factor is selected 0.5.
2. If the utility factor is less than 0.50 no throughput gain is achieved and user batteries can be run out fast.
3. At the telecom network operators side, the total price of the heterogeneous network is zero since no major changes are required in both networks.
4. At the user part, aggregate cost is one or two slots more latency and battery consumption for other users.
5. If the Hot-Spot selected very close to base station at a certain distance, interference of the other base stations will be limited then the overall throughput increases so much.
6. The suggested fairness issue, utility factor, is open ended subject because if the utility factor decreases down to zero, the heterogeneous network throughput will increases but the some of the users battery can easily run out. Further research will be done in this topic.
7. Different heterogeneous network structures may give better performances with respect to latency and throughput.

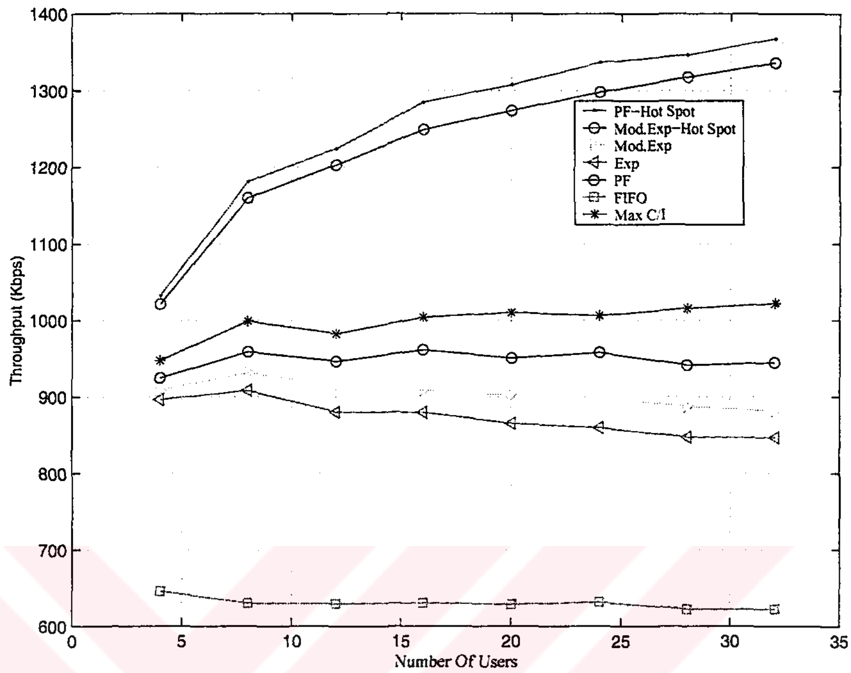

Figure 7.20: Hot Spot Position at 50 m Throughput versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

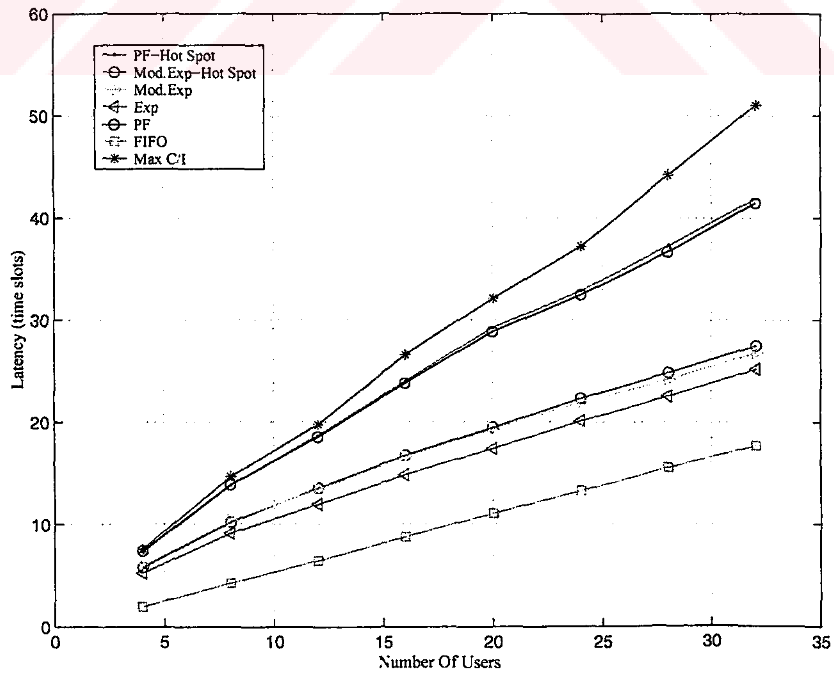

Figure 7.21: Hot Spot Position at 50 m Observed Latency versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

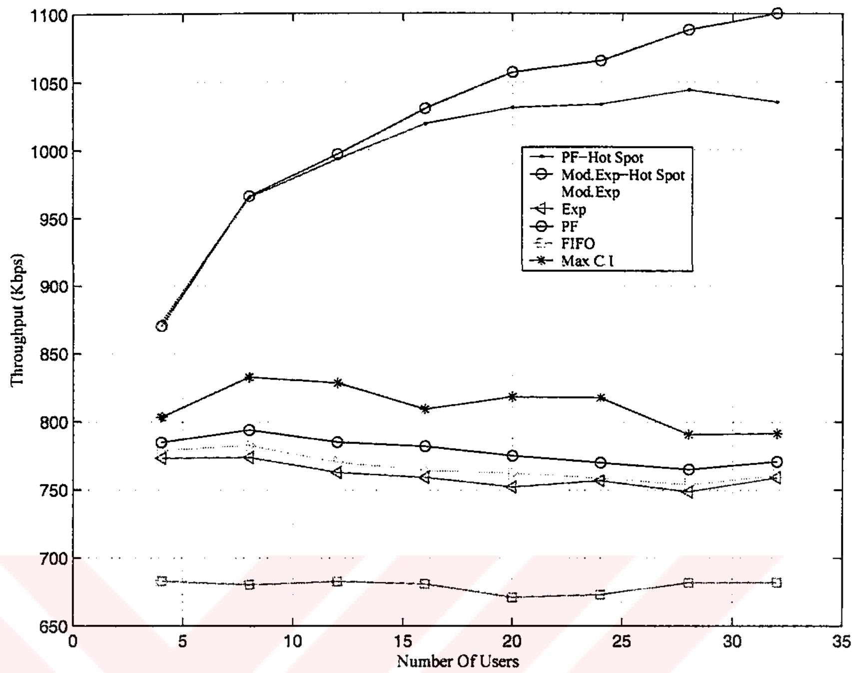

Figure 7.22: Hot Spot Position at 50 m Throughput versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

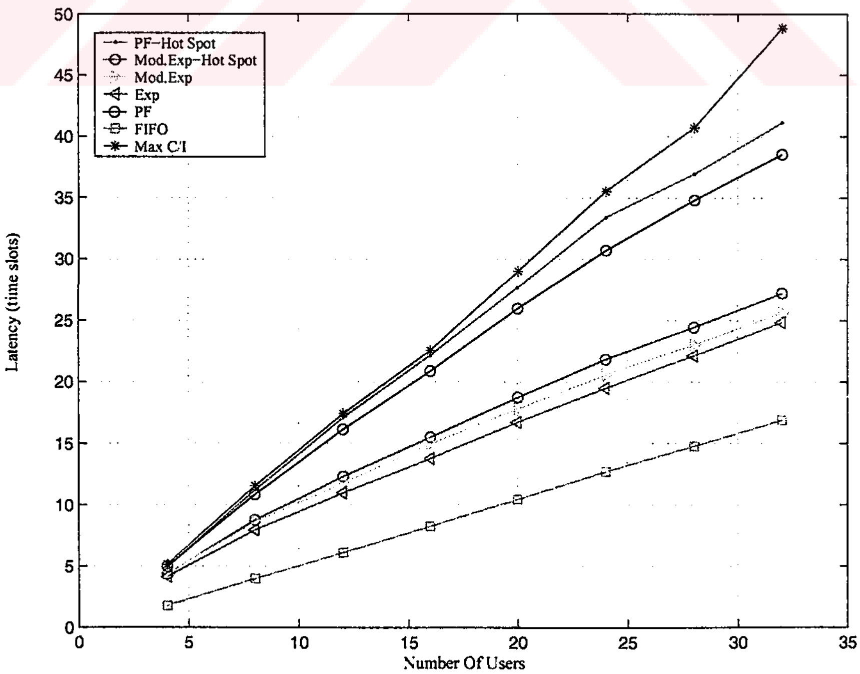

Figure 7.23: Hot Spot Position at 50 m Observed Latency versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

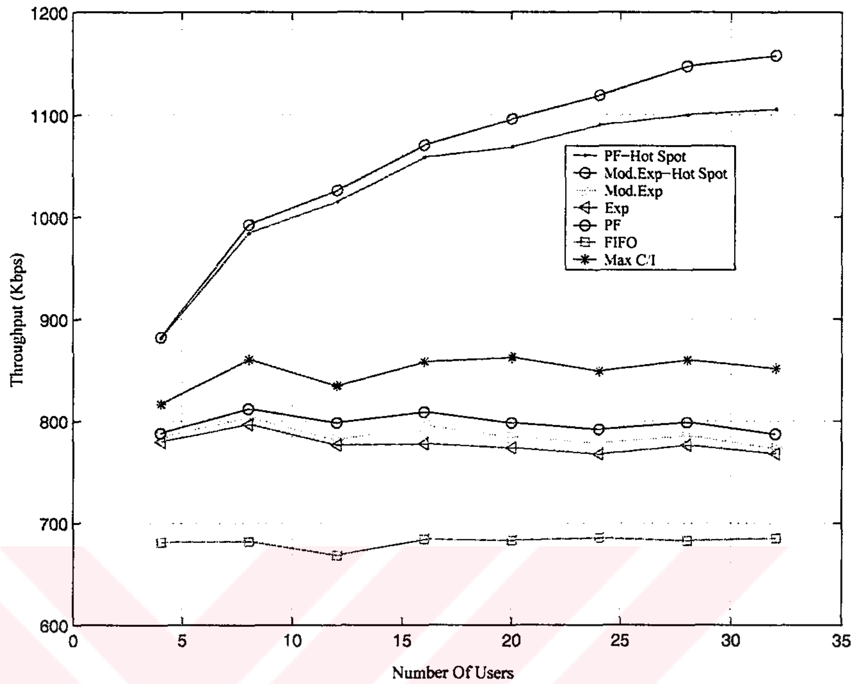

Figure 7.24: Hot Spot Position at 50 m Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

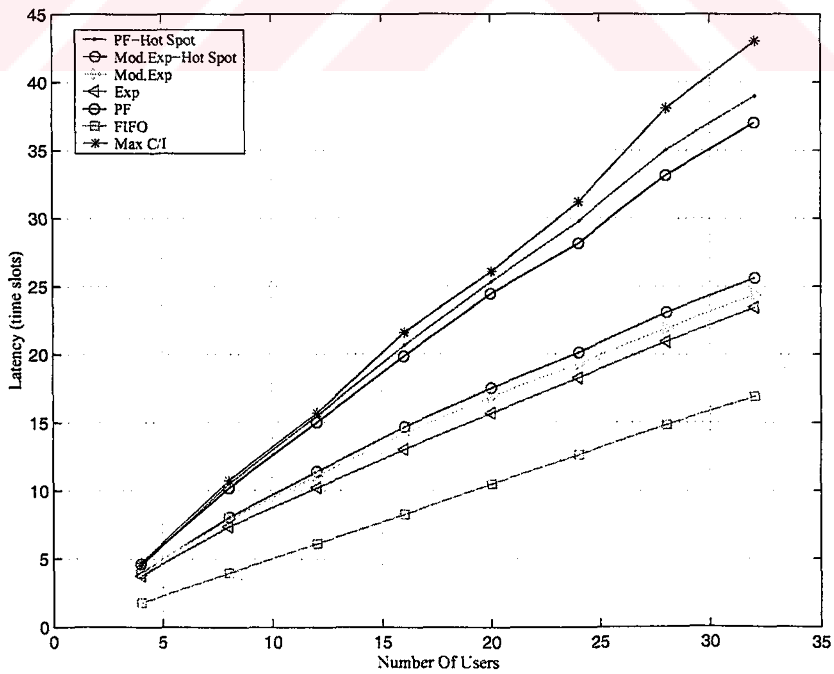

Figure 7.25: Hot Spot Position at 50 m Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

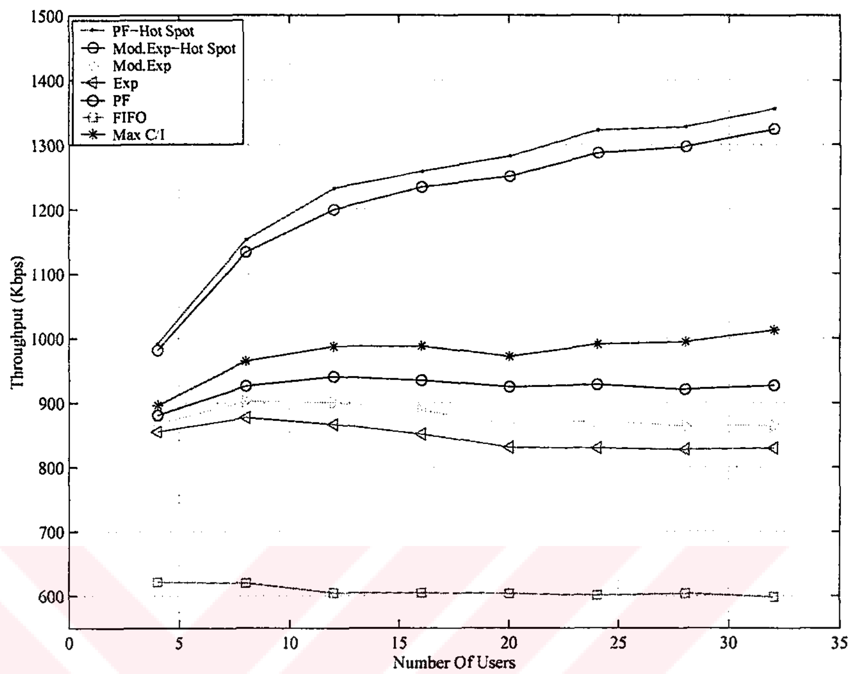

Figure 7.26: Hot Spot Position at 500 m Throughput versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

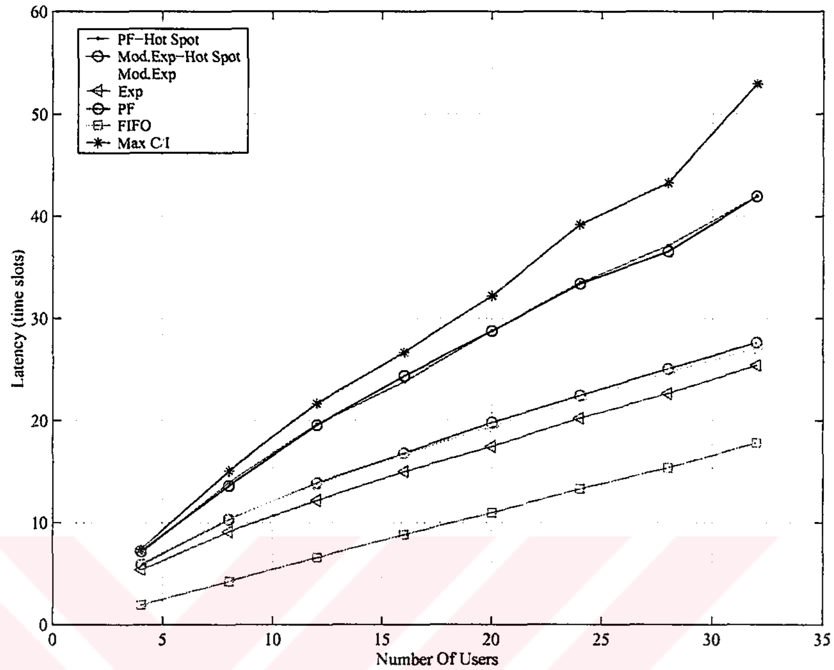

Figure 7.27: Hot Spot Position at 500 m Observed Latency versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

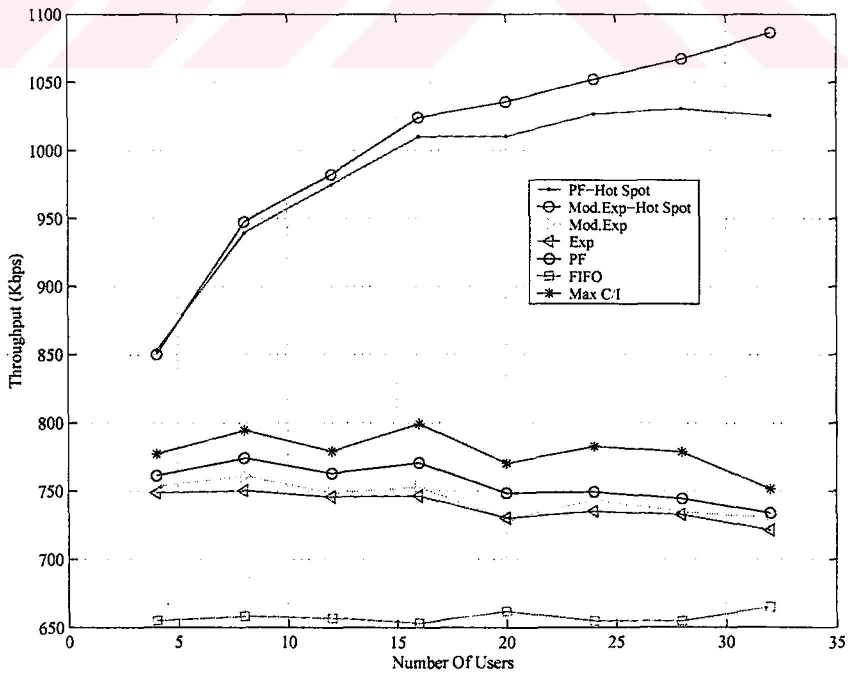

Figure 7.28: Hot Spot Position at 500 m Throughput versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

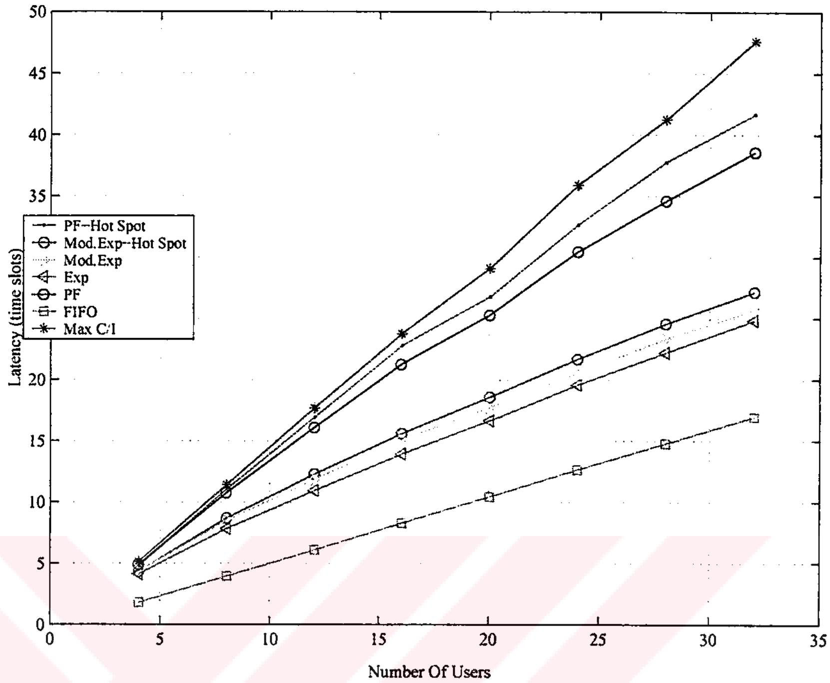

Figure 7.29: Hot Spot Position at 500 m Observed Latency versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

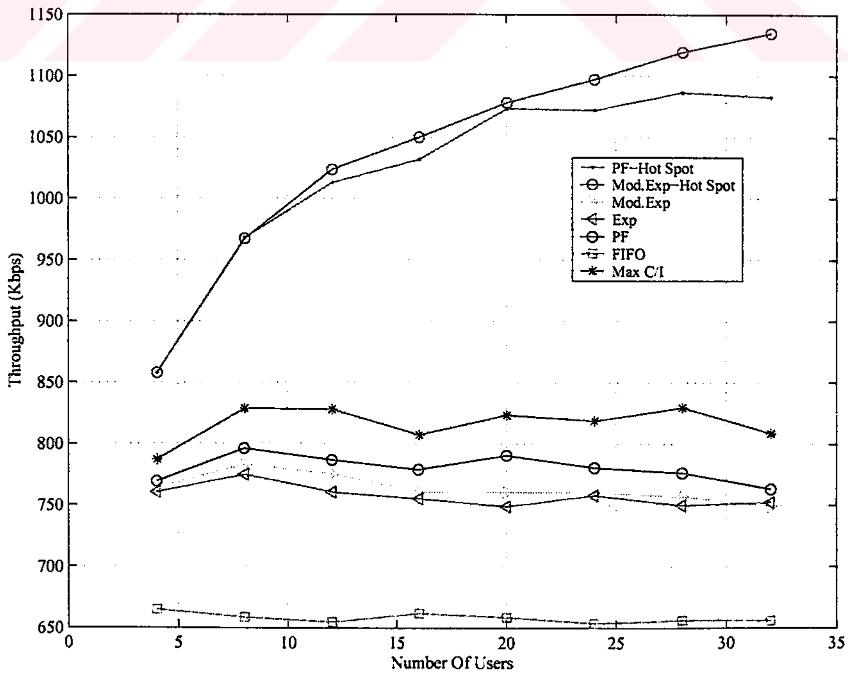

Figure 7.30: Hot Spot Position at 500 m Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

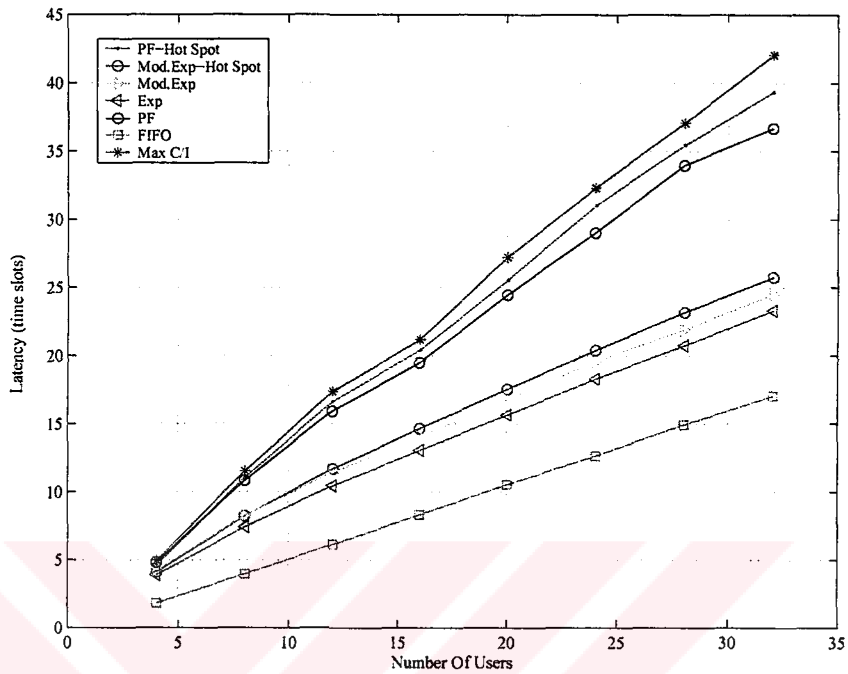

Figure 7.31: Hot Spot Position at 500 m Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

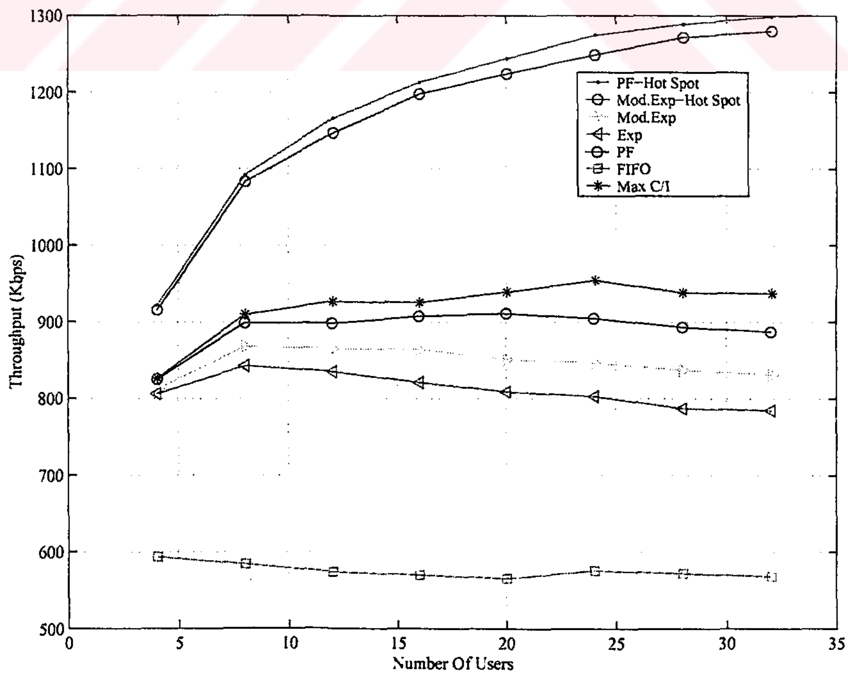

Figure 7.32: Hot Spot Position at 750 m Throughput versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

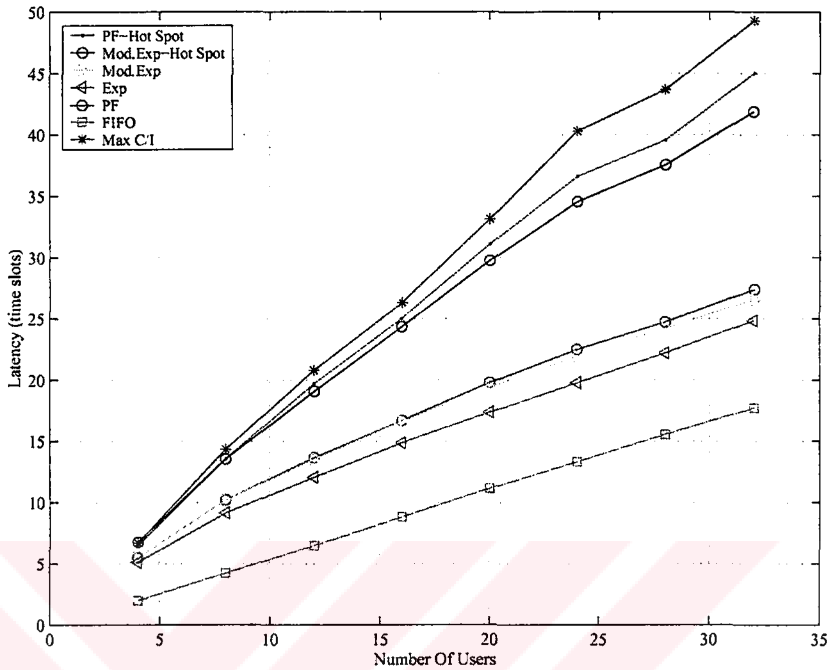

Figure 7.33: Hot Spot Position at 750 m Observed Latency versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

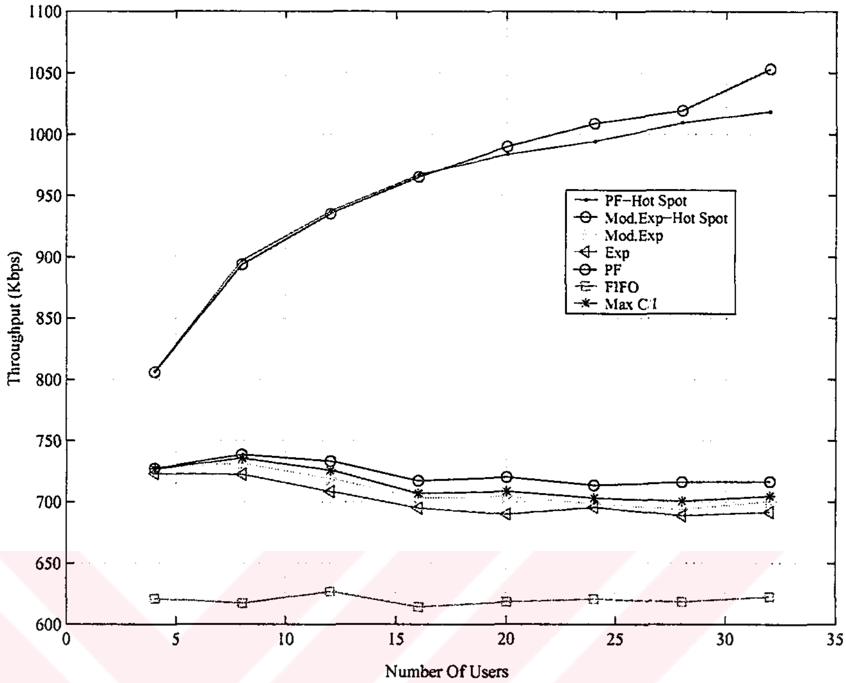

Figure 7.34: Hot Spot Position at 750 m Throughput versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

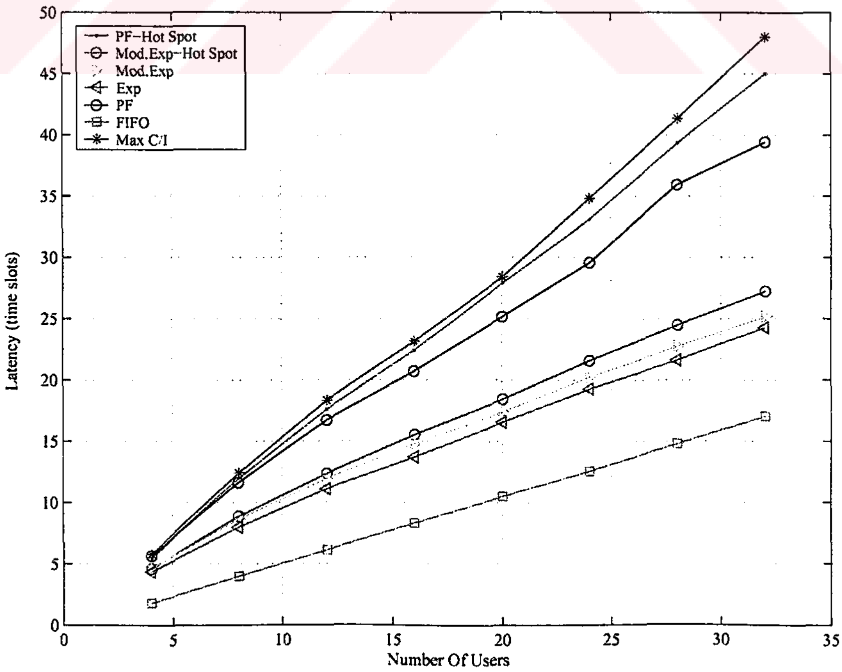

Figure 7.35: Hot Spot Position at 750 m Observed Latency versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

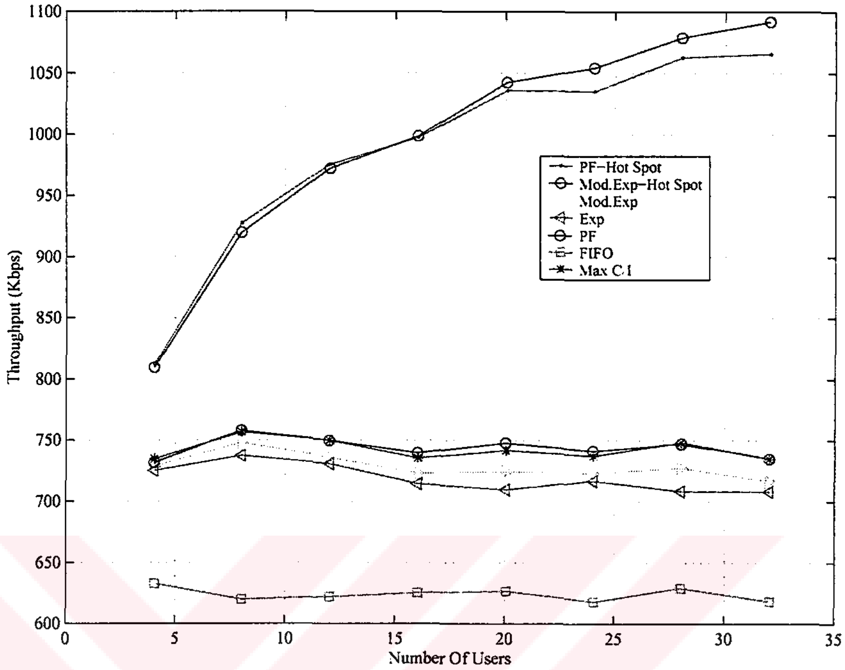

Figure 7.36: Hot Spot Position at 750 m Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

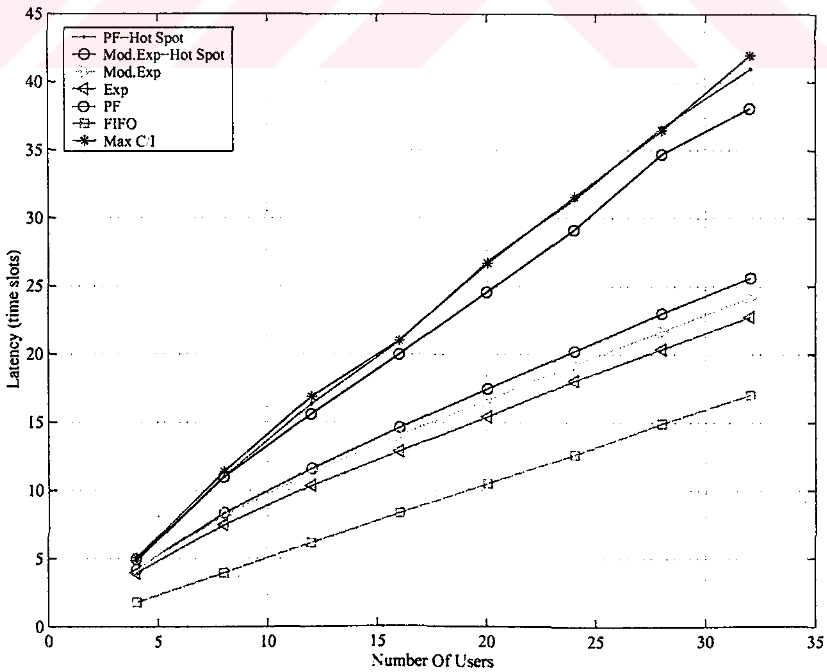

Figure 7.37: Hot Spot Position at 750 m Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

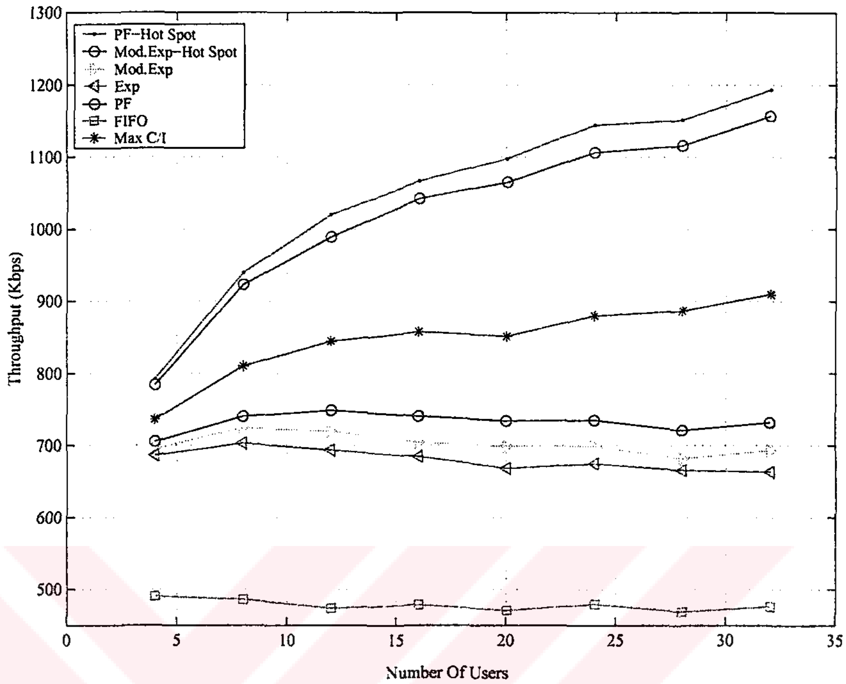

Figure 7.38: Hot Spot Position at 950 m Throughput versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

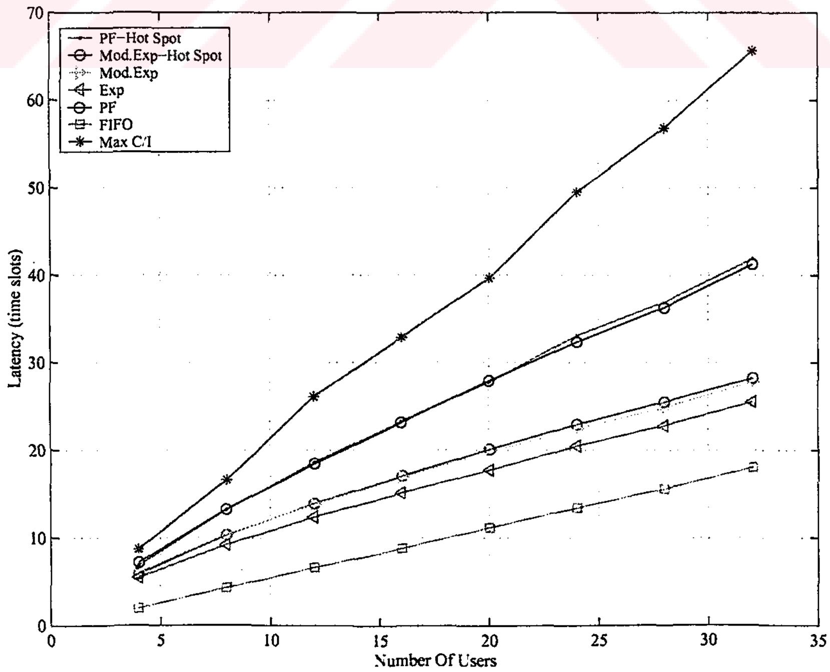

Figure 7.39: Hot Spot Position at 950 m Observed Latency versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

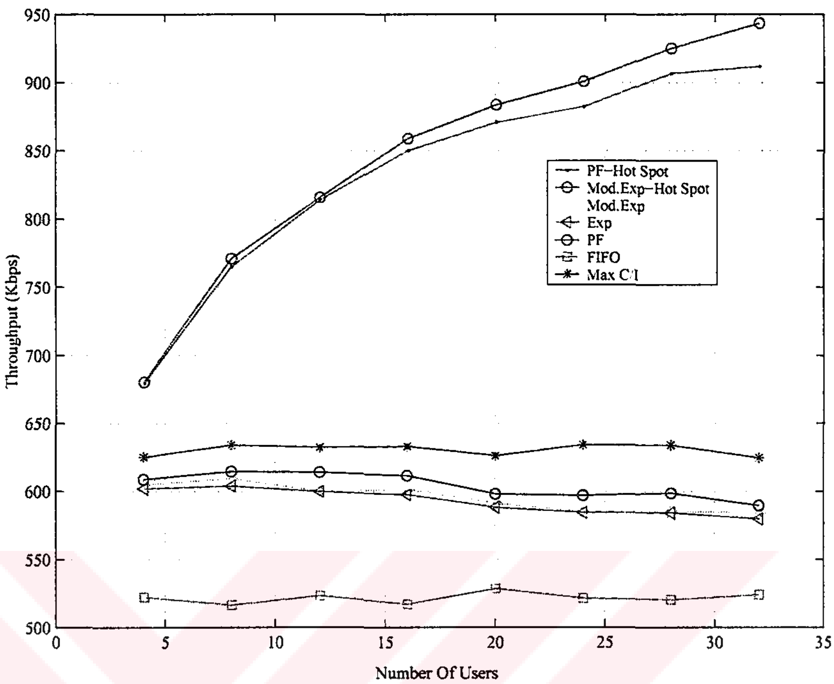

Figure 7.40: Hot Spot Position at 950 m Throughput versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

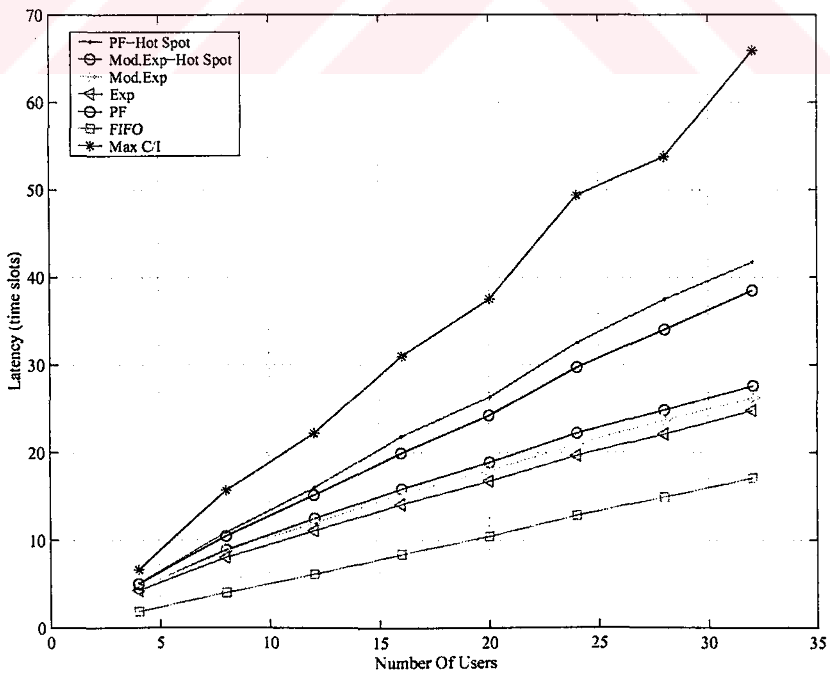

Figure 7.41: Hot Spot Position at 950 m Observed Latency versus Number of Users for the Heterogeneous Network for 30 km/hr and 0.5 km/hr users

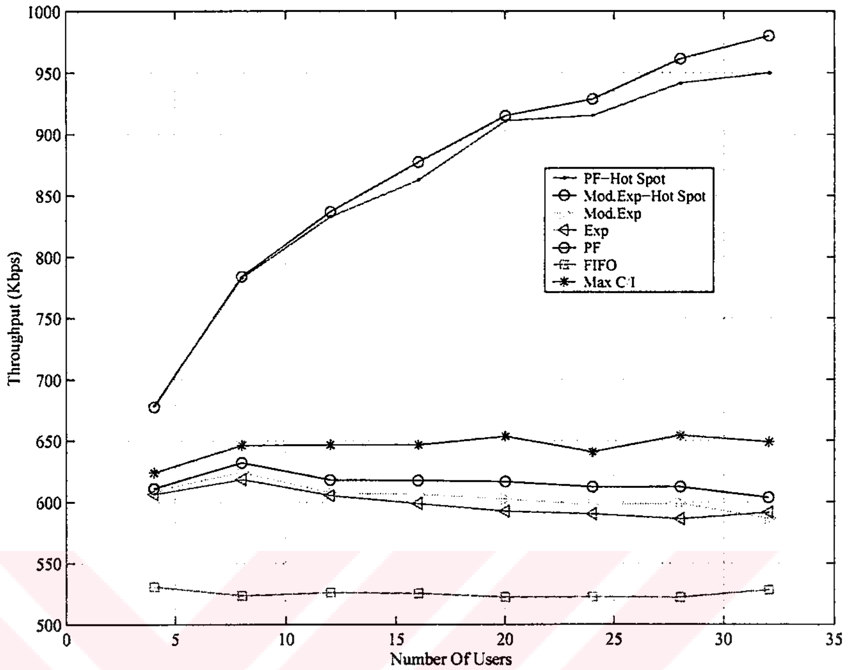

Figure 7.42: Hot Spot Position at 950 m Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

7.3 *Improved Access System for Wireless Packet Data Systems*

In the previous section, the findings proved that combination of IEEE 802.11a network with IS-856 system offers superior performance in terms of throughput. Furthermore, chapter 5 narrates mainly that the thesis proposed system, two users at a time is more efficient than one user at a time system, traditional IS-856, at the observed latency side. It can be easily seen that the combination of two users at a time system

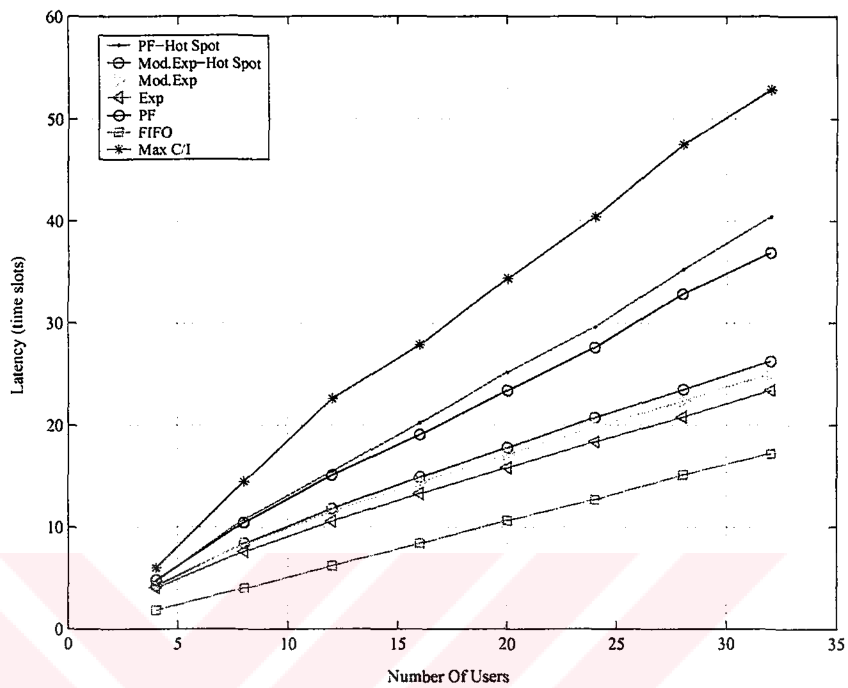

Figure 7.43: Hot Spot Position at 950 m Observed Latency versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

with IEEE 802.11a network is more valuable than the hybrid system that is explained previously.

7.3.1 Improved Access System Routing & Scheduling Algorithm (Mod.Exp.-Mod.Exp.-Hot Spot)

In respect of observations of the two users at a time scheduling in chapter 5, and heterogeneous network offerings in section 7.1 the optimal system has not only minimum latency figures but also maximum throughput. Therefore, the two users at a time system and IEEE 802.11a network should be combined. This association needs new type of scheduling and routing algorithm which is called Modified Exponential-Modified Exponential-Hot Spot(Mod.Exp.-Mod.Exp.-Hot Spot). The first term in the algorithm, *Modified Exponential*, depicts first user can be selected with using Modified Exponential-1 scheduler, and the second term is chosen again Modified Exponential-1 scheduler. The last term in the algorithm, *Hot Spot*, comes from probability of

Hot Spot usage. The new algorithm works for two user Hot Spot environment if the following conditions are satisfied:

1. The wireless channel conditions are nice to give a service for two users.
2. Both of the selected users present in the Hot-Spot.
3. Hot-Spot selected users' utility factors are greater or equal to 0.5.

Usually, only one user satisfies above three conditions then, solely one of the users will utilize the Hot-Spot environment, the other is used exclusively two users at a time system with the Modified Exponential-Modified Exponential scheme as explained chapter 5, if the wireless channel give chance to service a second user. When the number of users is low, rarely, no user fulfills the above provisions then system applies Modified Exponential-Modified Exponential scheduling.

7.4 New Access System Hot Spot Simulation Results

Newly proposed two users at a time system and IEEE 802.11a heterogeneous network structure are cogitated and analyzed the alteration in the experienced mixed system throughput and observed average latency values as a function of the users in the cell. Each Hot Spot position, throughput and latency values are obtained for cellular environment speeds:3 km/h, 30 km/h, and 100 km/h and the 0.5 km/h are the Hot Spot environment speed.

As stated before, the wireless channel is not perfectly estimated. It is obvious that as the Doppler frequency increases the system throughput the system throughput grows and the observed latency decreases. But, the delay between the transmission format request made by the mobile user and real transmission of the packet data is 3 slots in IS-856 system. Due to this 3 slot round-trip delay, the delayed feedback information is wounded as the Doppler increases and indifferent from real channel characteristics. To obtain proper heterogeneous system simulation results, the 3 slot round-trip delay is added to the feedback data. The scheduling algorithms under consideration in this chapter are the Modified Exponential-1, Exponential Rule, Proportional Fair, FIFO

Rule, and Maximum C/I rule as the five benchmark algorithms that show system performance only IS-856 system is used, Modified Exponential-Hot Spot that is the best heterogeneous system algorithm, and Modified Exponential-Modified Exponential-Hot Spot that is analyzed for new access system performance. The following subsections mixed system performance will be examined with different Hot Spot positions as seen in Figure 7.12- 7.15.

7.4.1 Hot Spot Position at 50 m

The simulation environment is the same as formerly expressed heterogeneous system, the IEEE 802.11a and IS-856 network. The 50% of the subscribers placed in the Hot Spot and their velocities are 0.5 km/hr. The place of the Hot Spot where the group stays during the simulation is shown in Figure 7.12. The rest of the users are employed only two users at a time system and their speeds are changed in three situations: the pedestrian, low mobile speed and fast vehicular speed correspond to 3 km/hr, 30 km/hr, and 100 km/hr, respectively.

¿From previous simulations in section 7.2 showed that the heterogeneous network structure schedulers′ performance is superior to pure IS-856 system schedulers′ performance. It is perceptible that the new access system is better than the heterogeneous system. Therefore, the comparison is made generally between the heterogeneous system and the new access system as seen in Figures 7.44-7.49.

In all channel conditions, the pure IS-856 system gives the worst performance independent of the employed scheduler. The comparison between the heterogeneous network and new access system can be achieved by analyzing the Modified Exponential-Modified Exponential-Hot Spot and Modified Exponential-1-Hot Spot schemes. If the 32 wireless subscribers present in the cellular system, the new access system supports 1376 kbps, 1165 kbps, and 1220 kbps for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, respectively. Yet, the heterogeneous network maintains only 1335 kbps, 1100 kbps, and 1157 kbps for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, severally. The deep impact has perceived at the latency side. The Mod.Exp.-Mod.Exp.-Hot Spot scheme experienced latencies are 17.32 time slots, 15.6

time slots, and 14.62 time slots for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, respectively. The Mod.Exp.-Hot Spot scheme experienced latencies are 27.43 time slots, 27.16 time slots, and 25.58 time slots for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, one by one. After completed of first part of the simulations; by using the new access system, the decrement in the latency figures is charming.

7.4.2 Hot Spot Position at 500 m

In this scenario, the Hot Spot is placed 500 m far from the base station as seen in Figure 7.13. The center of the Hot Spot is not far enough from the base station to increase experienced interference from neighbor base stations as seen in Figure 7.17, that is the why, observed signal to interference ratio is nearly equal to previous script. The new access system results 1360 kbps, 1200 kbps, and 1205 kbps for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, respectively. However, the heterogeneous network supports only 1323 kbps, 1086 kbps, and 1134 kbps for 3-km/hr channel, 30-km/hr channel, and 100-km/hr channel, severally. The latency values do not change so much; so, new access system is once more, more honorable performance than the heterogeneous network also classical IS-856 system as shown in Figure 7.50-7.55.

7.4.3 Hot Spot Position at 750 m

The position of the Hot Spot is 750 m as seen in Figure 7.14. As anticipated, the high signal to interference ratio is decreased by increasing distance between Hot Spot and the base station as seen in Figure 7.18.

The simulation results showed that new access system latency is superior to heterogeneous network with 32 users since Mod.Exp-Hot Spot latency is decreased 35% for 3 km/hr case, 42% for 30 km/hr event, and 42% for 100-km/hr channel. In addition to latency, the throughput is also increased approximately 6-8%. The price is only an extra battery usage in Hot Spot. In all channel conditions, once again, the traditional

IS-856 system schedulers result low throughput and high latency, the heterogeneous network yields high throughput and latency, and the new access system supports the highest throughput with a lowest latency figures as depicted in Figure 7.56-7.61.

7.4.4 Hot Spot Position at 950 m

The Hot Spot location is changed to 950 m as shown in Figure 7.15; the other parameters are the same. At this point, the interference signals from other base stations are strong enough to affect system performance badly is drawn in Figure 7.19. Once more, the new access system is the best performance both the IS-856 and the heterogeneous network depicted in Figure 7.38-7.67.

After completed all simulations, if the new system compare with the thesis proposed system, heterogeneous network, in chapter 7, the system throughput increases approximately 5-8% and the observed latency decreases around 40%. If the comparison is made between the classical IS-856 and the new access system the throughput increment around 60%, and the latency decrement 40% what the thesis contributes the IS-856 system.

7.5 Conclusion

The 3G carrier technologies cannot separately cover all the demands of the end-user in terms of coverage, bandwidth, quality of service (QoS) and cost. This chapter basically contributes the Cellular/WLAN integration via the IS-856 and IEEE 802.11a network. The integration of heterogeneous networks enables to increase data rates of IS-856 more than 50%. This is why 3G wireless network operators need public wireless LANs to serve the most demanding users in the most demanding locations. Second, this contribution will be helped by the boost of new mobile devices capable of receiving and transmitting two different frequencies: 2 GHz and 5 GHz. Finally, from findings of the heterogeneous networks, most important contribution of this chapter also the thesis, *New Access System*, will be explained in this chapter which increases system throughput approximately 60% and decreases latency figures around 40%.

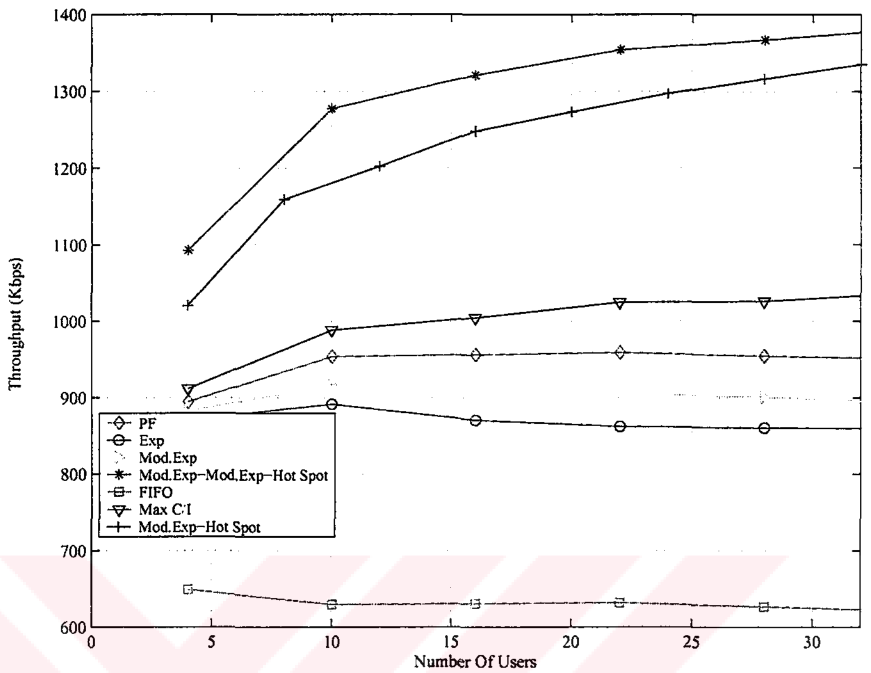

Figure 7.44: Hot Spot Position at 50 m Throughput versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

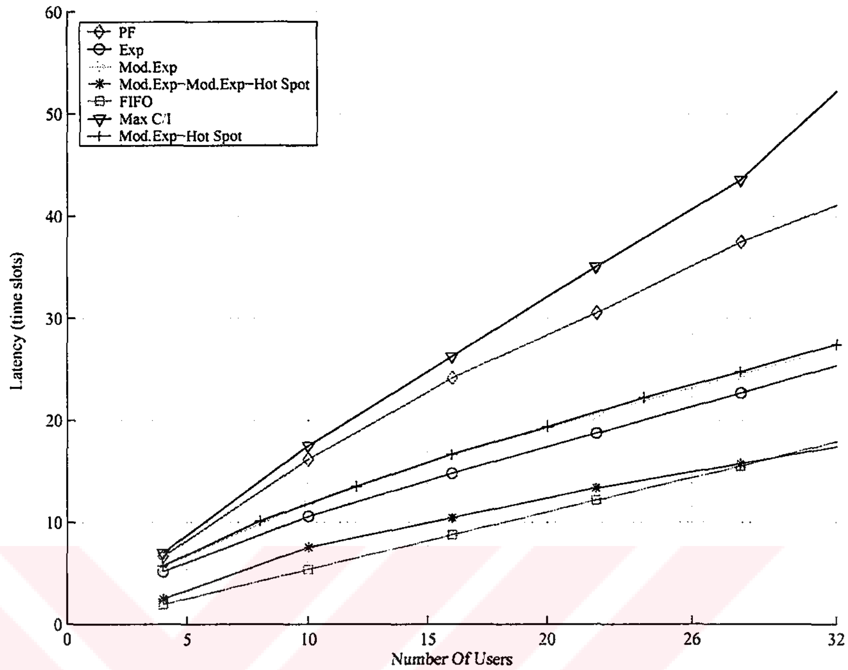

Figure 7.45: Hot Spot Position at 50 m Observed Latency versus Number of Users for New Access System for 3 km/hr and 0.5 km/hr users

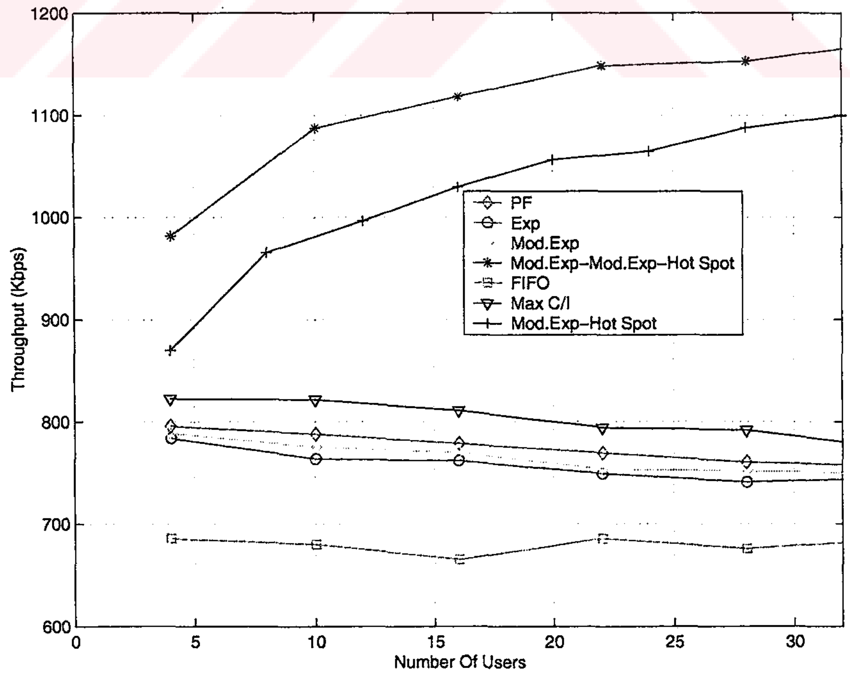

Figure 7.46: Hot Spot Position at 50 m Throughput versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

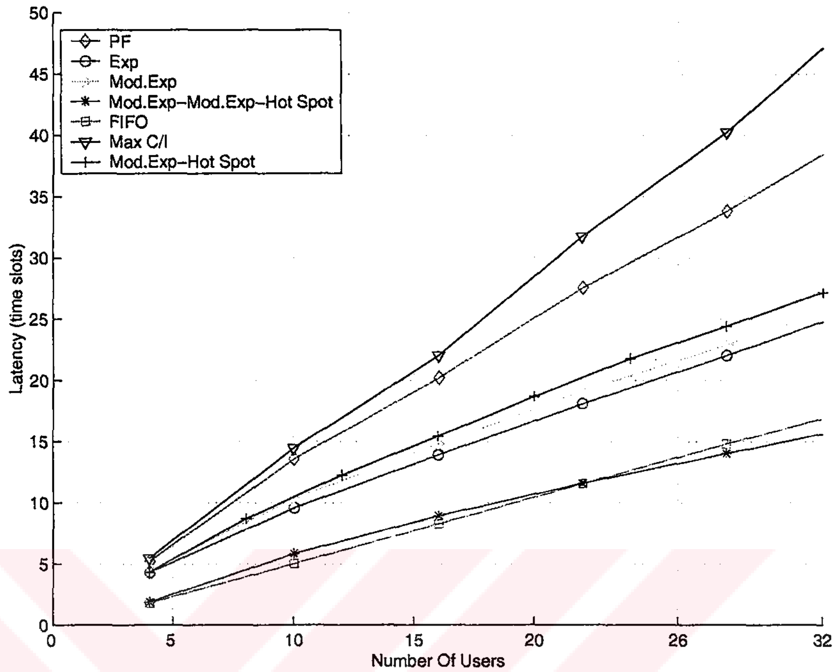

Figure 7.47: Hot Spot Position at 50 m Observed Latency versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

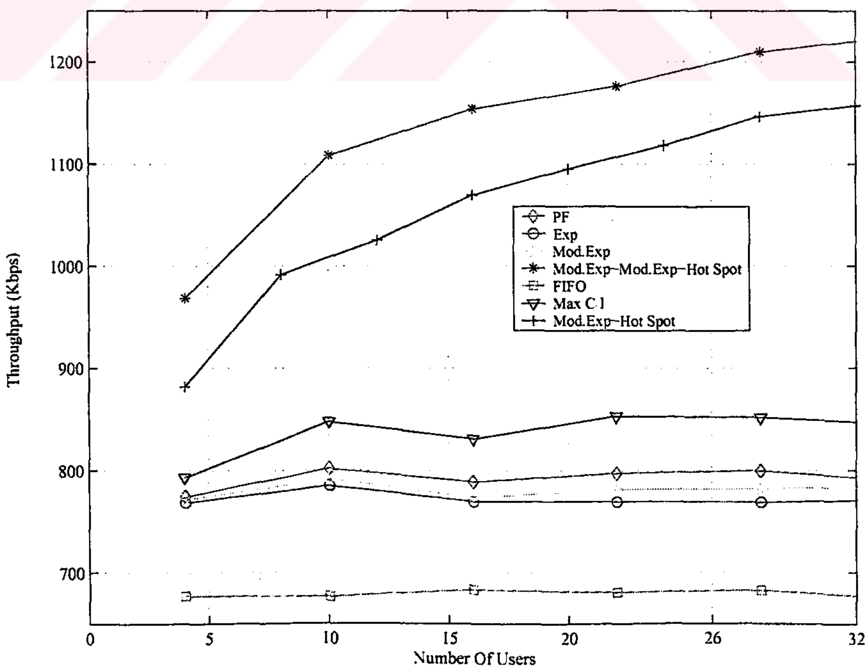

Figure 7.48: Hot Spot Position at 50 m Throughput versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

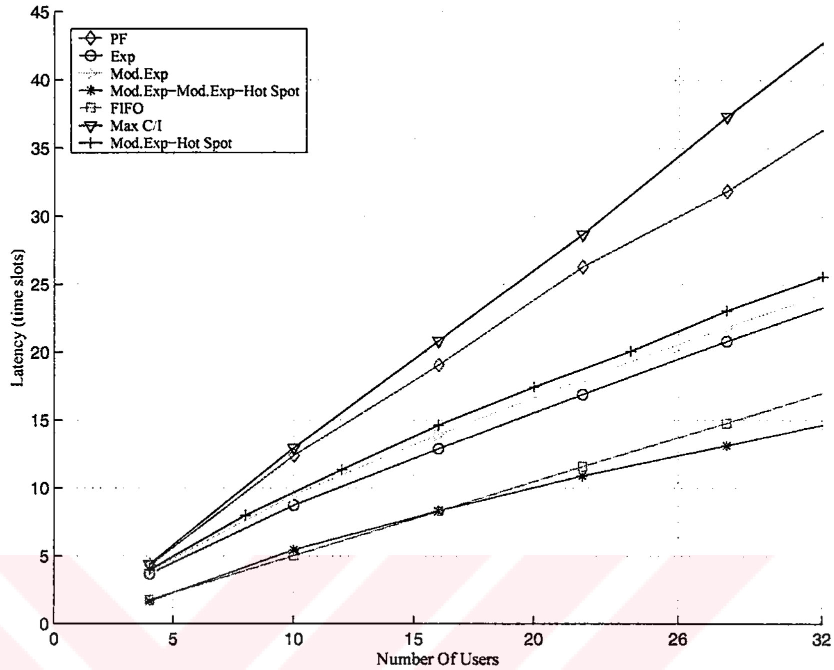

Figure 7.49: Hot Spot Position at 50 m Observed Latency versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

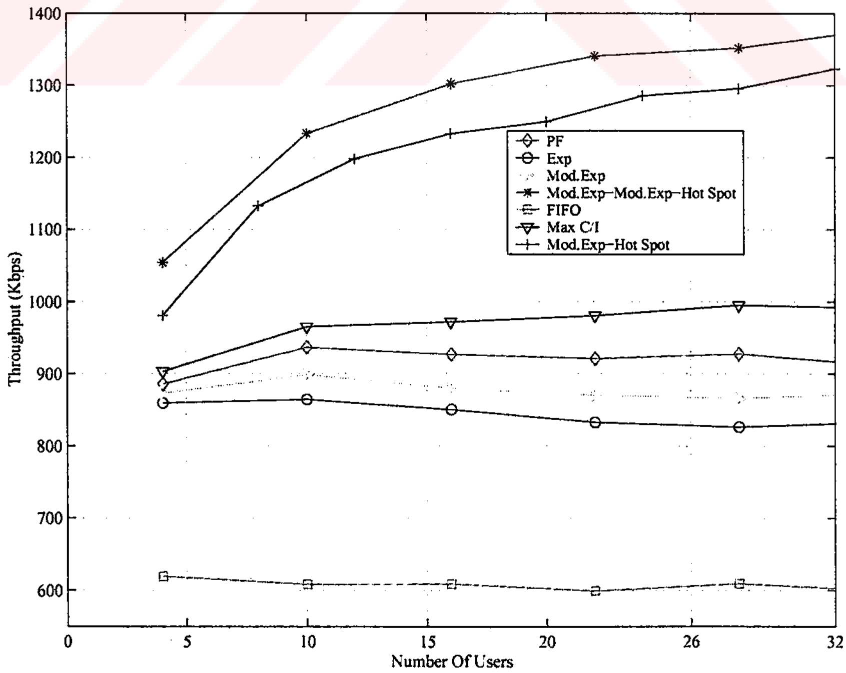

Figure 7.50: Hot Spot Position at 500 m Throughput versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

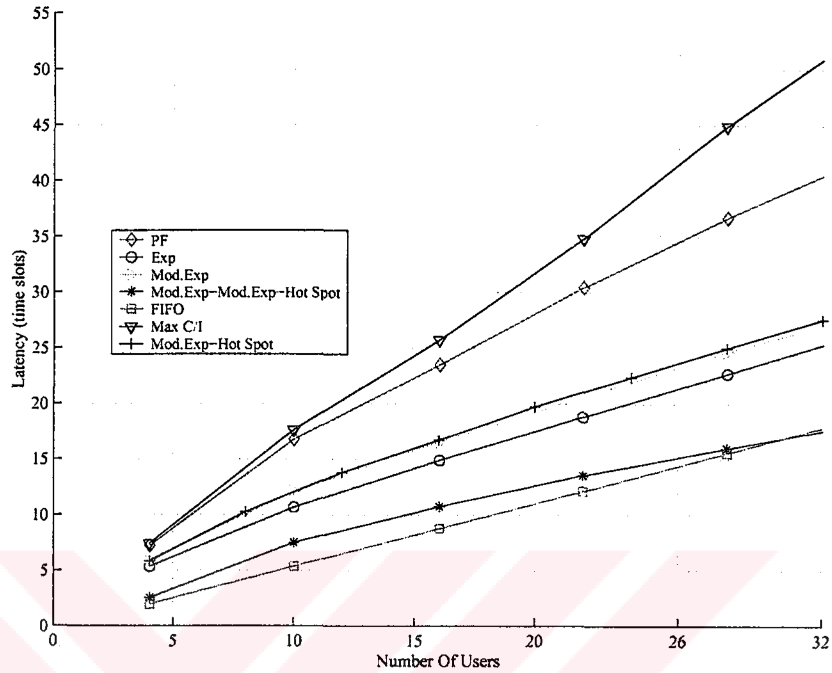

Figure 7.51: Hot Spot Position at 500 m Observed Latency versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

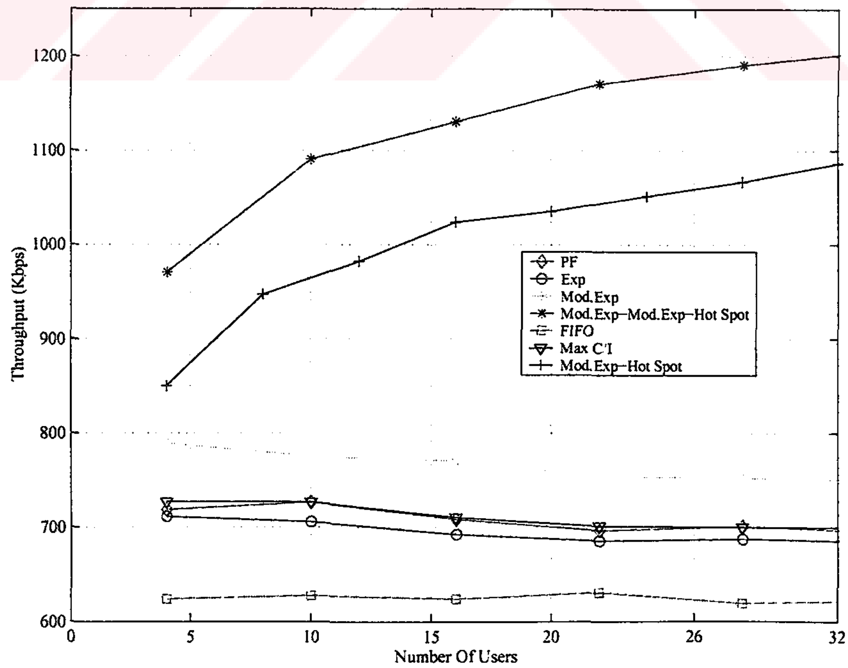

Figure 7.52: Hot Spot Position at 500 m Throughput versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

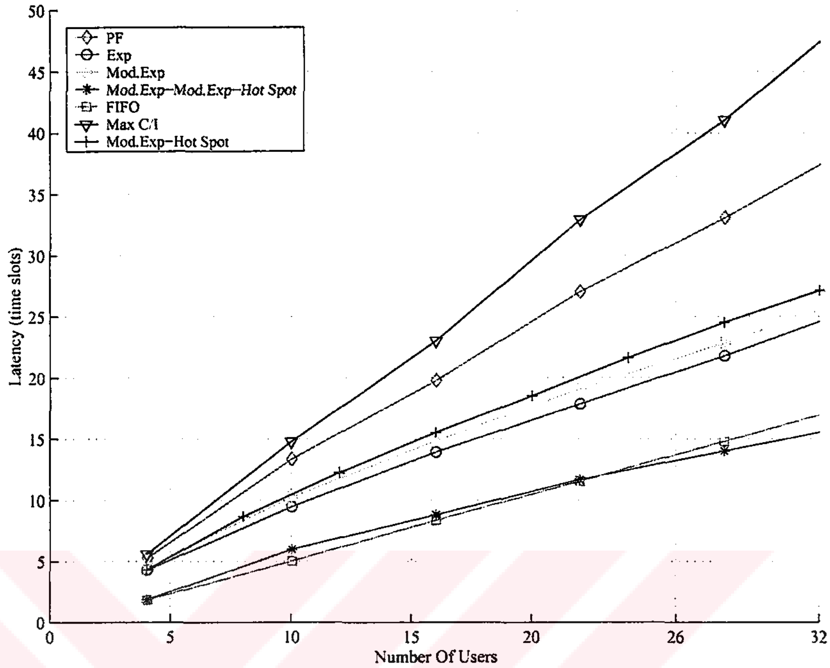

Figure 7.53: Hot Spot Position at 500 m Observed Latency versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

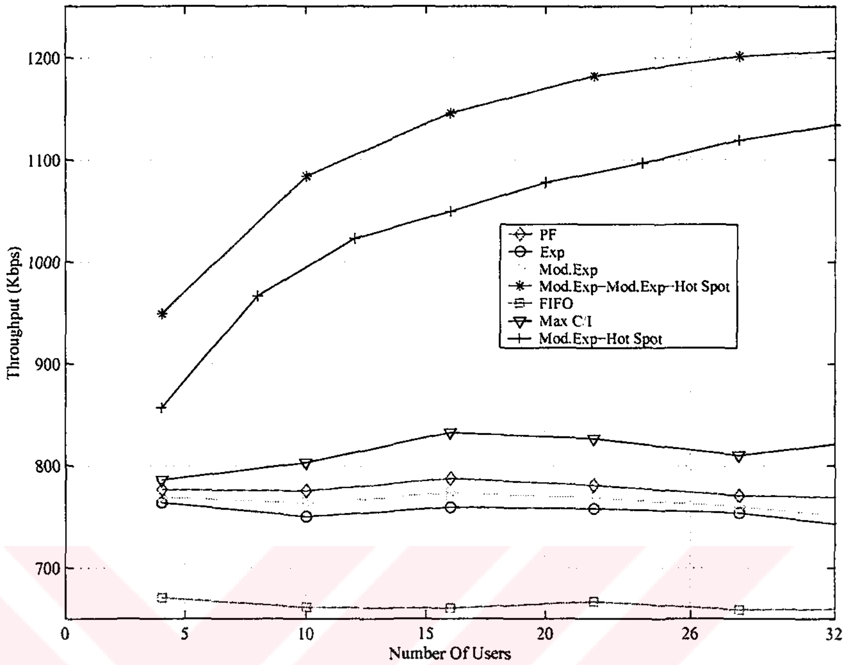

Figure 7.54: Hot Spot Position at 500 m Throughput versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

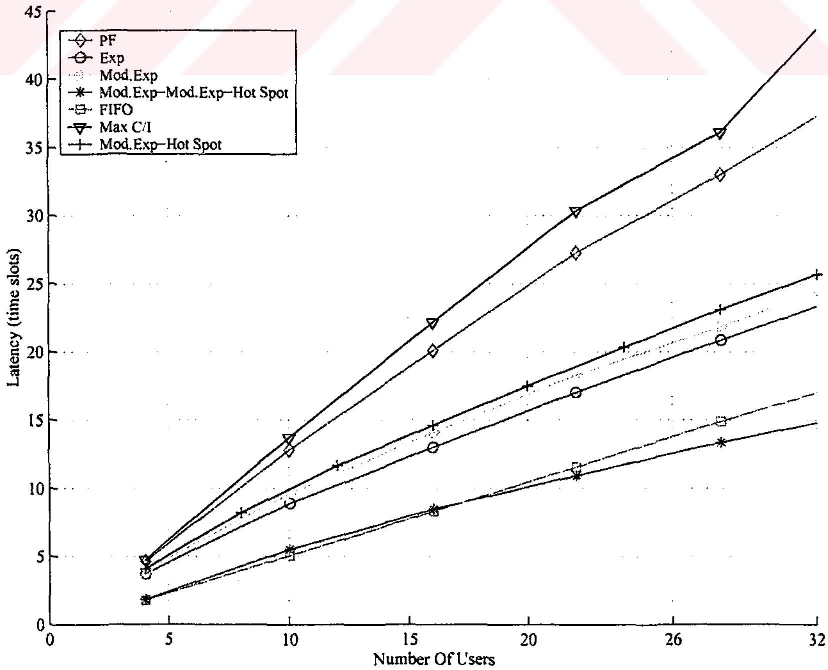

Figure 7.55: Hot Spot Position at 500 m Observed Latency versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

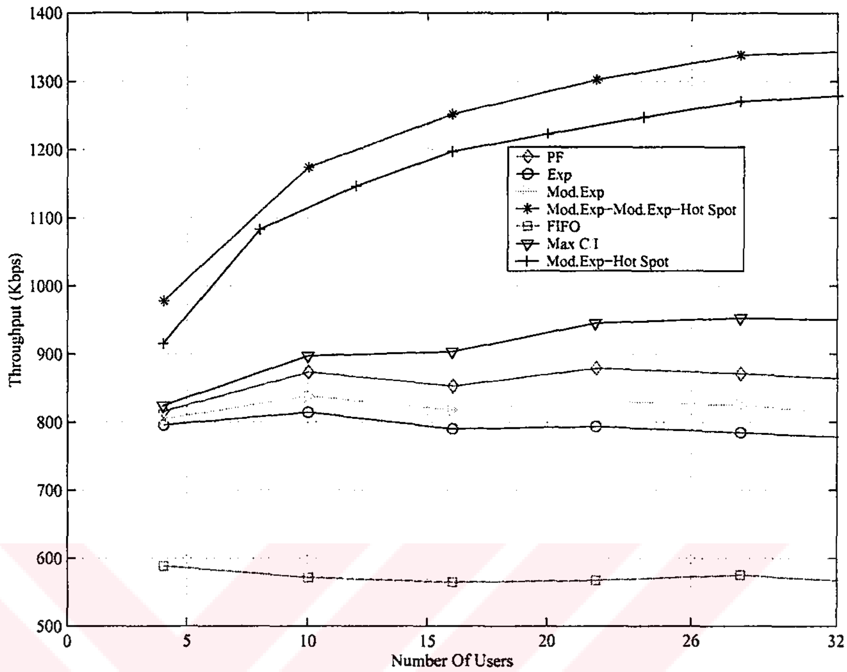

Figure 7.56: Hot Spot Position at 750 m Throughput versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

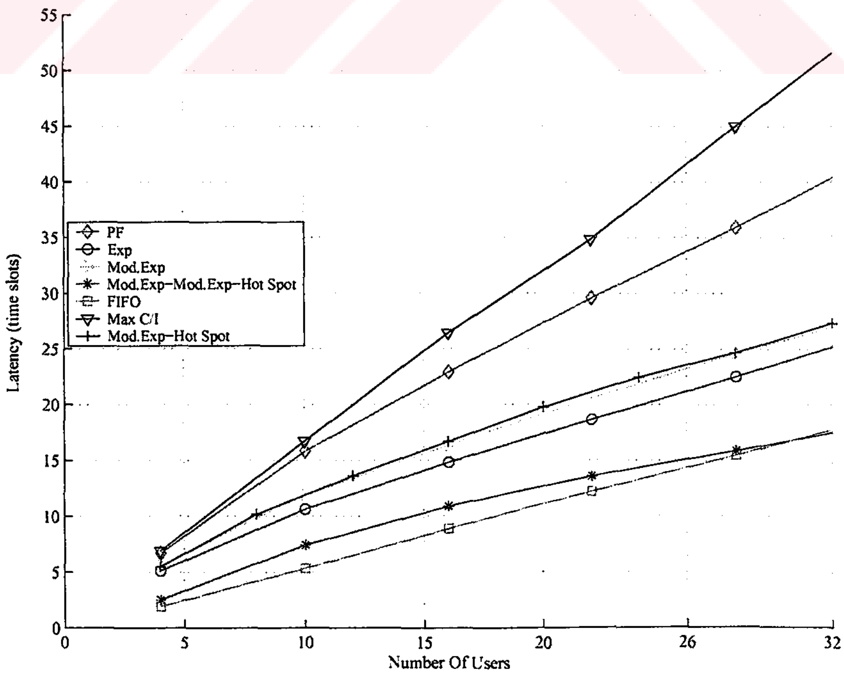

Figure 7.57: Hot Spot Position at 750 m Observed Latency versus Number of Users for the Heterogeneous Network for 3 km/hr and 0.5 km/hr users

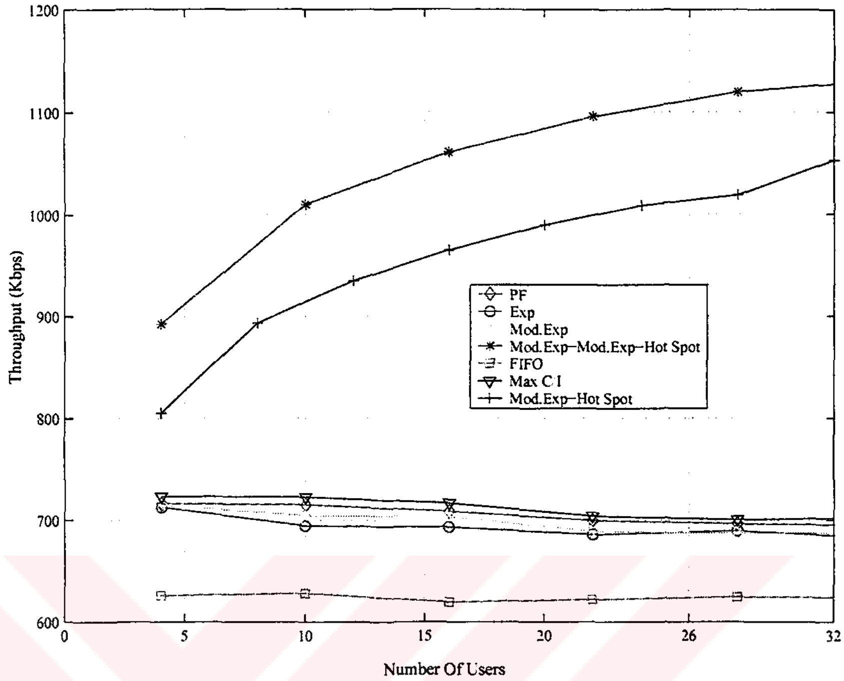

Figure 7.58: Hot Spot Position at 750 m Throughput versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

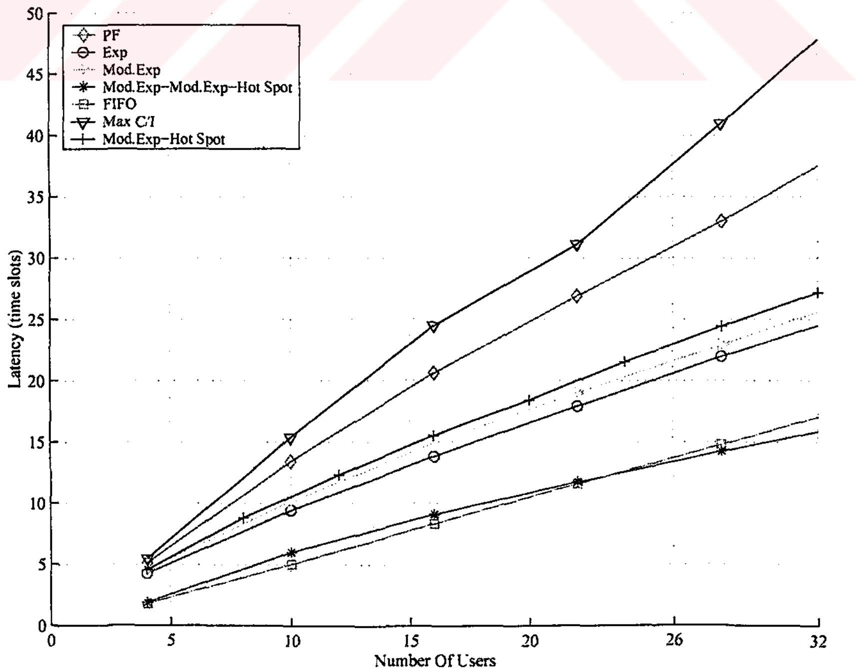

Figure 7.59: Hot Spot Position at 750 m Observed Latency versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

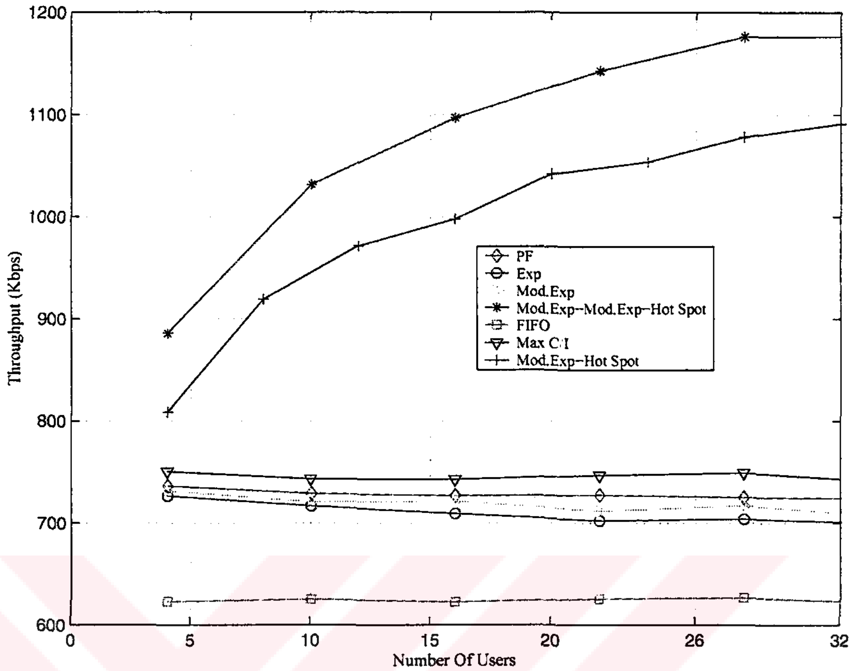

Figure 7.60: Hot Spot Position at 750 m Throughput versus Number of Users for the Heterogeneous Network for 100 km/hr and 0.5 km/hr users

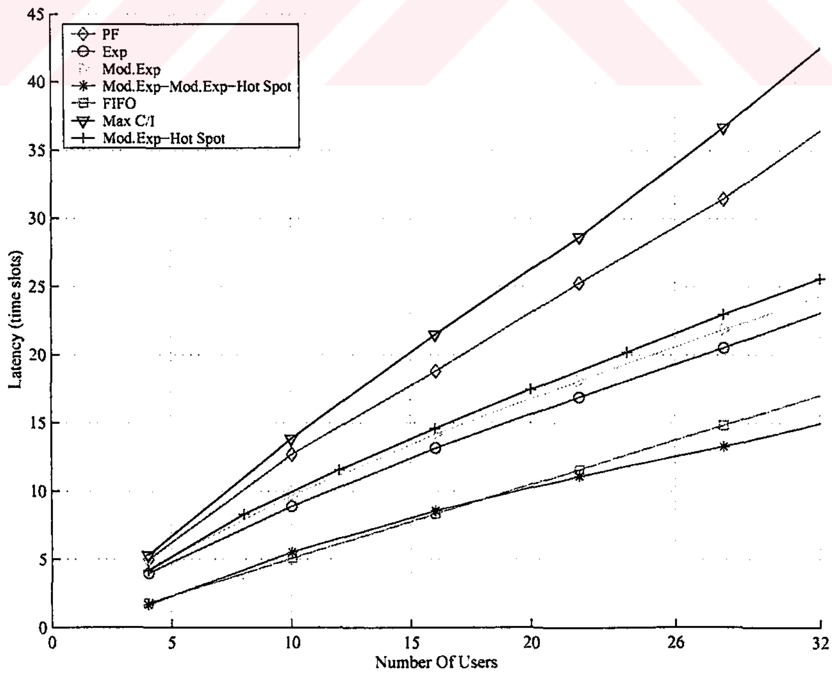

Figure 7.61: Hot Spot Position at 750 m Observed Latency versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

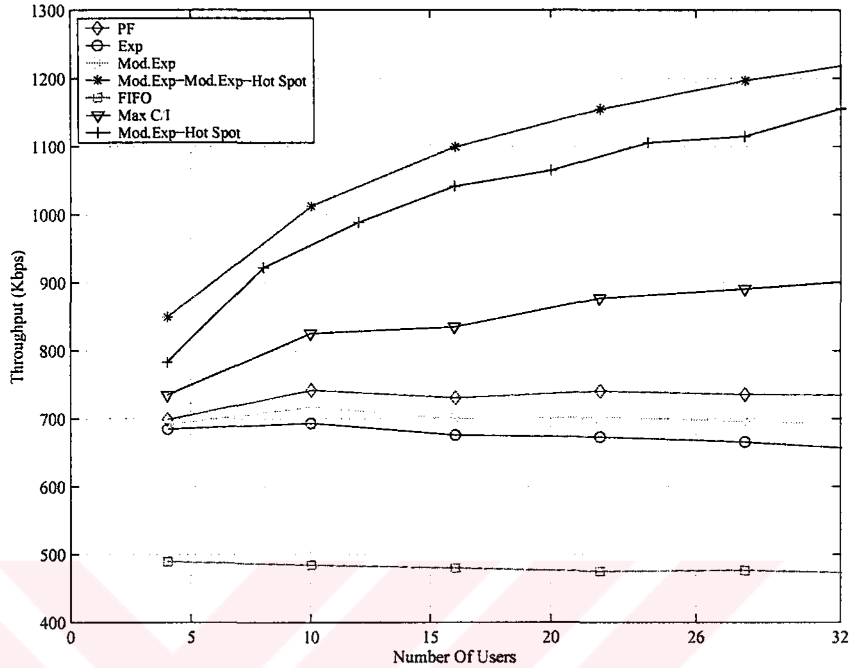

Figure 7.62: Hot Spot Position at 950 m Throughput versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

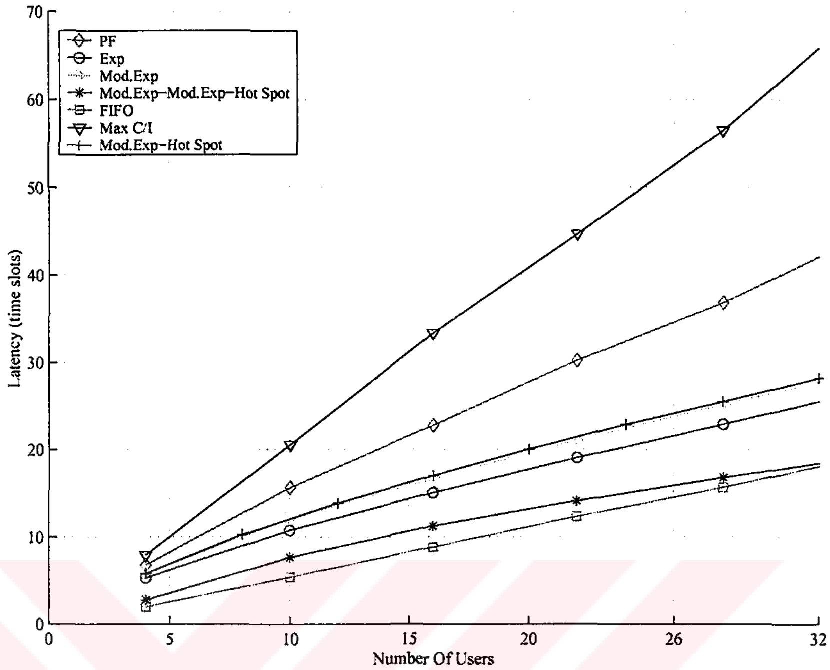

Figure 7.63: Hot Spot Position at 950 m Observed Latency versus Number of Users for the New Access System for 3 km/hr and 0.5 km/hr users

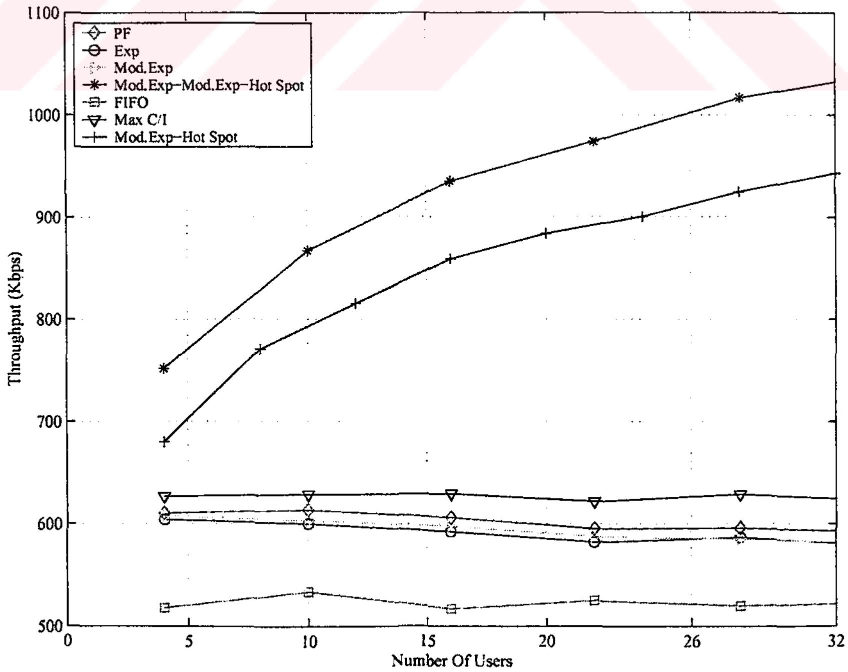

Figure 7.64: Hot Spot Position at 950 m Throughput versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

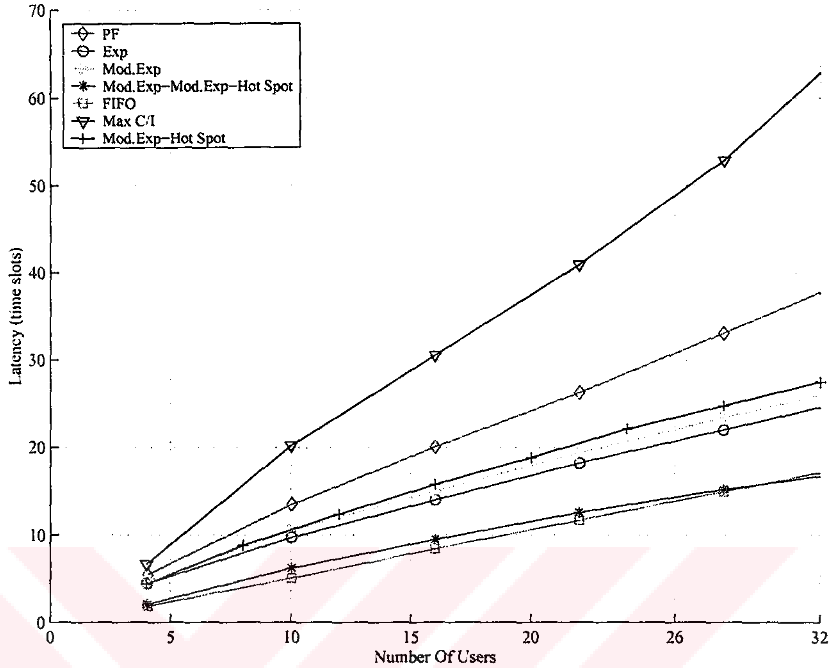

Figure 7.65: Hot Spot Position at 950 m Observed Latency versus Number of Users for the New Access System for 30 km/hr and 0.5 km/hr users

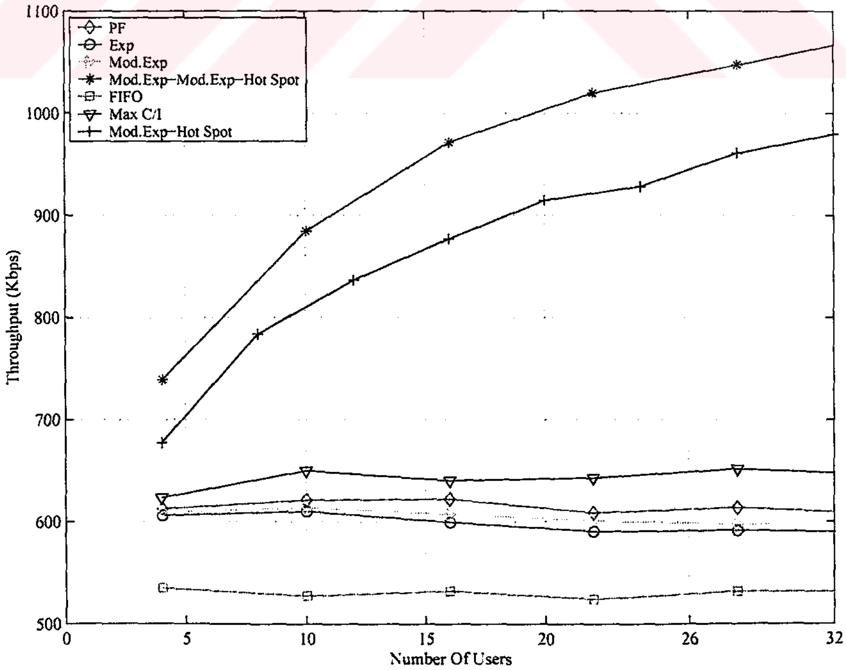

Figure 7.66: Hot Spot Position at 950 m Throughput versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

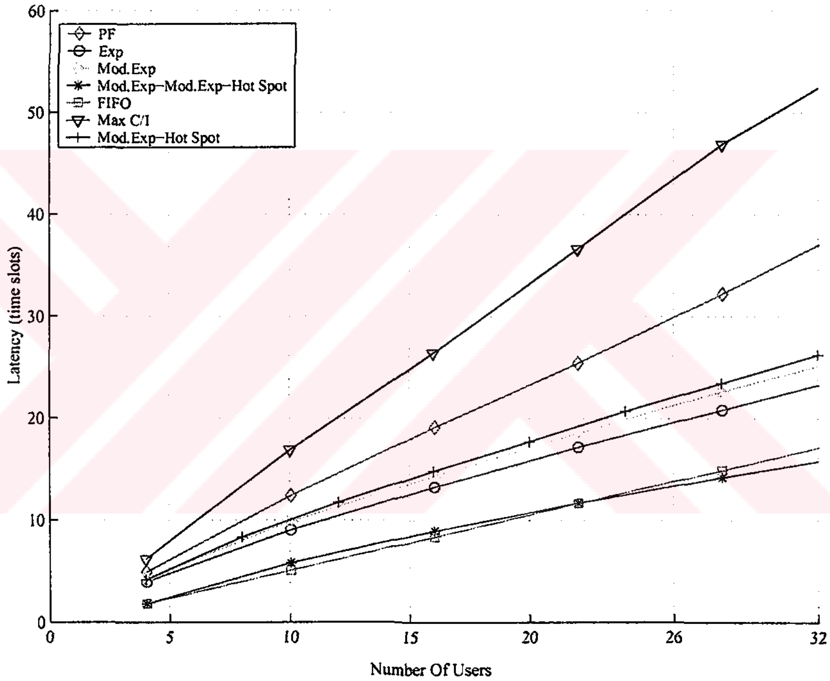

Figure 7.67: Hot Spot Position at 950 m Observed Latency versus Number of Users for the New Access System for 100 km/hr and 0.5 km/hr users

Chapter 8

CONCLUSIONS

The following list is a synopsis of the principle results adduced in the thesis.

1. The Proportional Fair scheduler that has become the de-facto companion to the deployed IS-856 system has unfair characteristics if different channel conditions are present in the system. Namely, the subscriber who has a low Doppler speed is exposed to higher latency figures.
2. In all channel conditions, 3 km/hr, 30 km/hr, and 100 km/hr, four of the suggested new algorithms, New Schedulers #1, 2, 3, & 5 provide for a very good overall performance in yielding good throughput values all the while maintaining latency figures close to those of the optimal values. Thesis suggests that among proposed schedulers, New Schedulers #1 can be selected for real applications.
3. Extensive simulations have been conducted and it is observed that it is possible to provide different services using the IS-856 system.
4. A possible way of providing multicast service provisioning in the IS-856 system is developed. It is observed that the physical layer support for multicast operation becomes very beneficial in increasing the spectral efficiency.
5. It is proposed to allow for simultaneous access to two users at a time, instead of the single user transmission as allowed in the IS-856 system. It is observed that such a scheme eliminates the high latency values of the IS-856 system to provide support for delay intolerant applications as well and additionally provides a modest increase the overall system throughput.
6. The envisioned WLAN and IS-856 cooperation increases the classical IS-856 network throughput by approximately 50% if approximately 50% of the IS-856 users have also access to the WLAN.

7. The fair power consumption problem in the WLAN and IS-856 cooperative networks is solved via adding a proper utility factor into the scheduling and routing algorithms.
8. The proper utility factor selection to prevent user battery consumption is discussed with detailed simulations.

8.1 Suggestions for Further Research

Presented here is a list of issues, which merit further consideration.

1. If the number of the antennas increase in the system, the overall system throughput will also increase. The use of multiple antennas at the transmitter and/or receiver has not been considered at all in this thesis.
2. New routing and scheduling algorithms should be developed for the WLAN and IS-856 cooperative system when multiple hops are allowed within the WLAN during the cooperation phase.
3. In the thesis, the lower layers of OSI have been considered. Further studies may be done for the upper layers of OSI. Cross-layer optimized scheduling algorithms may be developed that also take the network characteristics into account.

Appendix A

0.5 KM/HR CHANNEL FIR FILTER CONSTANTS

Here employing Parks-McClellan optimal equiripple 925 linear phase FIR filter coefficients represents the 0.5 km/hr wireless channel: -0.4737 0.0046 0.0005 -0.0007 -0.0019 -0.0026 -0.0044 -0.0043 -0.0029 -0.0018 -0.0034 -0.0054 -0.0025 -0.0013 -0.0041 -0.0035 -0.0003 0.0028 -0.0024 0.0020 -0.0053 -0.0030 -0.0061 -0.0079 -0.0105 -0.0064 -0.0086 -0.0063 -0.0096 -0.0068 -0.0064 -0.0042 -0.0062 -0.0090 -0.0051 - 0.0036 -0.0045 -0.0040 -0.0027 -0.0066 -0.0061 -0.0070 -0.0056 -0.0048 -0.0083 -0.0094 -0.0027 -0.0051 -0.0082 -0.0091 -0.0068 -0.0018 0.0000 -0.0011 -0.0047 -0.0095 -0.0027 -0.0080 -0.0093 -0.0097 -0.0085 -0.0143 -0.0101 -0.0127 -0.0068 -0.0094 -0.0051 -0.0091 -0.0078 -0.0090 - 0.0065 -0.0090 -0.0038 -0.0100 -0.0049 -0.0097 0.0099 -0.0077 -0.0302 -0.0105 -0.0134 -0.0090 -0.0119 -0.0088 -0.0095 -0.0096 -0.0109 -0.0063 -0.0093 -0.0092 -0.0111 -0.0094 -0.0100 - 0.0082 -0.0070 -0.0050 -0.0098 -0.0073 -0.0091 -0.0078 -0.0095 -0.0120 -0.0140 -0.0113 -0.0141 -0.0173 -0.0164 -0.0147 -0.0154 -0.0194 -0.0184 -0.0144 -0.0139 -0.0109 -0.0070 -0.0071 - 0.0091 -0.0047 -0.0083 -0.0069 -0.0084 -0.0096 -0.0126 -0.0088 -0.0077 -0.0079 -0.0116 -0.0122 -0.0160 -0.0099 -0.0134 -0.0077 -0.0134 -0.0097 -0.0136 -0.0116 -0.0162 -0.0131 -0.0098 - 0.0117 -0.0157 -0.0156 -0.0106 -0.0112 -0.0126 -0.0094 -0.0108 -0.0097 -0.0136 -0.0110 -0.0143 -0.0081 -0.0069 -0.0116 0.0113 -0.0083 -0.0151 -0.0130 -0.0153 -0.0118 -0.0127 -0.0080 -0.0082 -0.0074 -0.0108 -0.0048 -0.0054 -0.0072 -0.0066 -0.0038 -0.0036 -0.0108 -0.0087 -0.0105 - 0.0117 -0.0090 -0.0102 -0.0093 -0.0077 -0.0039 -0.0052 -0.0052 -0.0067 -0.0097 -0.0113 -0.0065 -0.0063 -0.0121 -0.0130 -0.0128 -0.0132 -0.0125 -0.0096 -0.0082 -0.0069 -0.0089 -0.0076 - 0.0041 -0.0042 -0.0038 -0.0075 -0.0068 -0.0068 -0.0046 -0.0062 -0.0072 -0.0043 -0.0028 -0.0059 -0.0055 -0.0040 -0.0019 -0.0022 0.0001 -0.0057 -0.0044 -0.0063 -0.0022 -0.0076 -0.0059 -0.0082 -0.0116 -0.0105 -0.0040 -0.0071 -0.0036 -0.0096 -0.0083 -0.0115 -0.0032 -0.0138 -0.0057 0.0022 -0.0061 -0.0001 -0.0083 -0.0093 -0.0076 -0.0035 -0.0027 -0.0052 -0.0069 -0.0064 -0.0057 - 0.0042 -0.0066 -0.0063 -0.0038 -0.0037 -0.0017 -0.0059 -0.0010 -0.0056 -0.0053 -0.0024 -0.0041 -0.0063 -0.0038

-0.0049 -0.0031 -0.0020 -0.0013 -0.0013 0.0013 0.0018 -0.0021 -0.0050 -0.0009 -0.0037
-0.0076 -0.0042 -0.0057 -0.0030 -0.0034 -0.0024 0.0002 -0.0003 -0.0025 -0.0010 0.0004
0.0028 0.0026 -0.0010 0.0006 0.0038 -0.0019 -0.0045 -0.0031 -0.0055 -0.0031 -0.0052 -
0.0056 - 0.0003 0.0005 0.0004 0.0003 0.0038 0.0043 0.0049 0.0043 0.0029 0.0027 0.0066
0.0011 -0.0025 0.0017 0.0011 0.0020 -0.0076 0.0028 0.0001 0.0042 0.0067 0.0012 0.0037
0.0058 0.0044 0.0031 -0.0008 0.0025 -0.0008 -0.0012 -0.0015 0.0004 0.0033 0.0040 0.0040
0.0003 0.0027 0.0031 0.0019 0.0003 0.0036 0.0055 -0.0017 0.0028 -0.0001 0.0040 0.0059
0.0068 0.0027 0.0030 0.0027 0.0063 0.0077 0.0087 0.0083 0.0103 0.0106 0.0092 0.0080
0.0068 0.0086 0.0061 0.0061 0.0045 0.0063 0.0063 0.0038 0.0039 0.0031 0.0077 0.0089
0.0104 0.0099 0.0096 0.0072 0.0101 0.0086 0.0083 0.0116 0.0112 0.0088 0.0137 0.0107
0.0096 0.0112 0.0116 0.0134 0.0151 0.0141 0.0124 0.0103 0.0104 0.0165 0.0145 0.0105
0.0187 0.0132 0.0179 0.0119 0.0185 0.0151 0.0164 0.0128 0.0123 0.0145 0.0153 0.0145
0.0161 0.0156 0.0138 0.0146 0.0163 0.0123 0.0138 0.0147 0.0160 0.0159 0.0161 0.0154
0.0170 0.0166 0.0192 0.0154 0.0167 0.0169 0.0166 0.0157 0.0151 0.0145 0.0179 0.0175
0.0211 0.0214 0.0206 0.0233 0.0248 0.0203 0.0250 0.0250 0.0289 0.0294 0.0238 0.0274
0.0240 0.0233 0.0263 0.0261 0.0274 0.0268 0.0286 0.0293 0.0318 0.0349 0.0326 0.0355
0.0363 0.0397 0.0442 0.0423 0.0450 0.0476 0.0541 0.0519 0.0582 0.0654 0.0721 0.0821
0.0978 0.1142 0.1648 0.5253 0.1648 0.1142 0.0978 0.0821 0.0721 0.0654 0.0582 0.0519
0.0541 0.0476 0.0450 0.0423 0.0442 0.0397 0.0363 0.0355 0.0326 0.0349 0.0318 0.0293
0.0286 0.0268 0.0274 0.0261 0.0263 0.0233 0.0240 0.0274 0.0238 0.0294 0.0289 0.0250
0.0250 0.0203 0.0248 0.0233 0.0206 0.0214 0.0211 0.0175 0.0179 0.0145 0.0151 0.0157
0.0166 0.0169 0.0167 0.0154 0.0192 0.0166 0.0170 0.0154 0.0161 0.0159 0.0160 0.0147
0.0138 0.0123 0.0163 0.0146 0.0138 0.0156 0.0161 0.0145 0.0153 0.0145 0.0123 0.0128
0.0164 0.0151 0.0185 0.0119 0.0179 0.0132 0.0187 0.0105 0.0145 0.0165 0.0104 0.0103
0.0124 0.0141 0.0151 0.0134 0.0116 0.0112 0.0096 0.0107 0.0137 0.0088 0.0112 0.0116
0.0083 0.0086 0.0101 0.0072 0.0096 0.0099 0.0104 0.0089 0.0077 0.0031 0.0039 0.0038
0.0063 0.0063 0.0045 0.0061 0.0061 0.0086 0.0068 0.0080 0.0092 0.0106 0.0103 0.0083
0.0087 0.0077 0.0063 0.0027 0.0030 0.0027 0.0068 0.0059 0.0040 -0.0001 0.0028 -0.0017
0.0055 0.0036 0.0003 0.0019 0.0031 0.0027 0.0003 0.0040 0.0040 0.0033 0.0004 -0.0015
-0.0012 -0.0008 0.0025 -0.0008 0.0031 0.0044 0.0058 0.0037 0.0012 0.0067 0.0042 0.0001
0.0028 -0.0076 0.0020 0.0011 0.0017 -0.0025 0.0011 0.0066 0.0027 0.0029 0.0043 0.0049

0.0043 0.0038 0.0003 0.0004 0.0005 -0.0003 -0.0056 -0.0052 -0.0031 -0.0055 -0.0031
-0.0045 -0.0019 0.0038 0.0006 -0.0010 0.0026 0.0028 0.0004 -0.0010 -0.0025 -0.0003
0.0002 -0.0024 -0.0034 -0.0030 -0.0057 -0.0042 -0.0076 -0.0037 -0.0009 -0.0050 -0.0021
0.0018 0.0013 -0.0013 -0.0013 -0.0020 -0.0031 -0.0049 -0.0038 -0.0063 -0.0041 -0.0024
-0.0053 -0.0056 -0.0010 -0.0059 - 0.0017 -0.0037 -0.0038 -0.0063 -0.0066 -0.0042 -0.0057
-0.0064 -0.0069 -0.0052 -0.0027 -0.0035 -0.0076 -0.0093 -0.0083 -0.0001 -0.0061 0.0022
-0.0057 -0.0138 -0.0032 -0.0115 -0.0083 -0.0096 -0.0036 -0.0071 -0.0040 -0.0105 -0.0116
-0.0082 -0.0059 -0.0076 -0.0022 -0.0063 -0.0044 - 0.0057 0.0001 -0.0022 -0.0019 -0.0040
-0.0055 -0.0059 -0.0028 -0.0043 -0.0072 -0.0062 -0.0046 -0.0068 -0.0068 -0.0075 -0.0038
-0.0042 -0.0041 -0.0076 -0.0089 -0.0069 -0.0082 -0.0096 - 0.0125 -0.0132 -0.0128 -0.0130
-0.0121 -0.0063 -0.0065 -0.0113 -0.0097 -0.0067 -0.0052 -0.0052 -0.0039 -0.0077 -0.0093
-0.0102 -0.0090 -0.0117 -0.0105 -0.0087 -0.0108 -0.0036 -0.0038 - 0.0066 -0.0072 -0.0054
-0.0048 -0.0108 -0.0074 -0.0082 -0.0080 -0.0127 -0.0118 -0.0153 -0.0130 -0.0151 -0.0083
0.0113 -0.0116 -0.0069 -0.0081 -0.0143 -0.0110 -0.0136 -0.0097 -0.0108 -0.0094 -0.0126
-0.0112 -0.0106 -0.0156 -0.0157 -0.0117 -0.0098 -0.0131 -0.0162 -0.0116 -0.0136 - 0.0097
-0.0134 -0.0077 -0.0134 -0.0099 -0.0160 -0.0122 -0.0116 -0.0079 -0.0077 -0.0088 -0.0126
-0.0096 -0.0084 -0.0069 -0.0083 -0.0047 -0.0091 -0.0071 -0.0070 -0.0109 -0.0139 -0.0144
- 0.0184 -0.0194 -0.0154 -0.0147 -0.0164 -0.0173 -0.0141 -0.0113 -0.0140 -0.0120 -0.0095
-0.0078 -0.0091 -0.0073 -0.0098 -0.0050 -0.0070 -0.0082 -0.0100 -0.0094 -0.0111 -0.0092
-0.0093 - 0.0063 -0.0109 -0.0096 -0.0095 -0.0088 -0.0119 -0.0090 -0.0134 -0.0105 -0.0302
-0.0077 0.0099 -0.0097 -0.0049 -0.0100 -0.0038 -0.0090 -0.0065 -0.0090 -0.0078 -0.0091
-0.0051 -0.0094 - 0.0068 -0.0127 -0.0101 -0.0143 -0.0085 -0.0097 -0.0093 -0.0080 -0.0027
-0.0095 -0.0047 -0.0011 0.0000 -0.0018 -0.0068 -0.0091 -0.0082 -0.0051 -0.0027 -0.0094
-0.0083 -0.0048 -0.0056 -0.0070 -0.0061 -0.0066 -0.0027 -0.0040 -0.0045 -0.0036 -0.0051
-0.0090 -0.0062 -0.0042 -0.0064 - 0.0068 -0.0096 -0.0063 -0.0086 -0.0064 -0.0105 -0.0079
-0.0061 -0.0030 -0.0053 0.0020 -0.0024 0.0028 -0.0003 -0.0035 -0.0041 -0.0013 -0.0025
-0.0054 -0.0034 -0.0018 -0.0029 -0.0043 -0.0044 -0.0026 -0.0019 -0.0007 0.0005 0.0046
-0.4737.

Appendix B

3 KM/HR CHANNEL FIR FILTER CONSTANTS

The following numbers showed that the 3 km/hr wireless channel via Parks-McClellan optimal equiripple 925 linear phase FIR filter coefficients: -0.3372 0.0217 0.0201 0.0202 0.0138 0.0194 0.0132 0.0108 0.0096 0.0157 0.0078 0.0080 0.0082 0.0044 0.0060 0.0082 0.0035 0.0077 0.0092 0.0099 0.0018 0.0025 0.0028 0.0094 0.0057 0.0022 -0.0009 0.0026 0.0076 0.0047 0.0027 0.0037 -0.0005 0.0024 0.0018 0.0000 0.0001 0.0011 0.0043 0.0026 0.0019 -0.0013 -0.0004 -0.0062 -0.0079 -0.0057 -0.0028 -0.0012 -0.0020 -0.0064 -0.0055 -0.0017 0.0004 -0.0016 -0.0061 -0.0028 -0.0037 -0.0026 -0.0014 -0.0062 -0.0009 -0.0042 - 0.0015 -0.0035 -0.0037 -0.0078 -0.0015 -0.0025 -0.0012 -0.0031 -0.0042 -0.0060 -0.0060 - 0.0027 -0.0053 -0.0057 0.0002 -0.0095 -0.0192 -0.0045 -0.0074 -0.0070 -0.0126 0.0006 -0.0045 -0.0075 -0.0138 -0.0121 -0.0148 -0.0103 -0.0095 -0.0053 -0.0098 -0.0079 -0.0074 -0.0003 - 0.0030 0.0023 -0.0005 -0.0032 -0.0032 0.0052 0.0024 0.0074 0.0013 0.0066 0.0100 0.0099 0.0100 0.0080 0.0086 0.0100 0.0055 0.0101 0.0082 0.0084 0.0117 0.0120 0.0075 0.0044 0.0053 0.0112 0.0001 0.0020 0.0002 0.0020 0.0011 -0.0029 -0.0013 0.0010 0.0032 0.0013 -0.0003 0.0003 -0.0029 0.0048 -0.0013 0.0007 0.0006 0.0007 0.0029 0.0003 -0.0003 -0.0004 -0.0025 0.0018 -0.0040 0.0009 -0.0022 0.0017 -0.0007 0.0033 0.0011 0.0025 0.0191 0.0043 0.0069 0.0019 0.0020 0.0028 0.0033 0.0013 0.0010 -0.0014 -0.0033 -0.0009 0.0023 -0.0007 -0.0031 0.0015 0.0023 0.0040 0.0016 0.0023 -0.0010 -0.0008 - 0.0038 -0.0018 -0.0058 -0.0012 -0.0019 - 0.0030 -0.0012 -0.0024 -0.0027 -0.0018 -0.0064 -0.0020 -0.0046 -0.0071 -0.0082 -0.0031 -0.0069 -0.0042 -0.0099 -0.0114 -0.0098 -0.0093 -0.0103 -0.0079 -0.0144 -0.0122 -0.0121 -0.0120 - 0.0106 -0.0101 -0.0127 -0.0146 -0.0098 -0.0060 -0.0072 -0.0057 -0.0059 -0.0118 -0.0098 -0.0042 -0.0091 -0.0028 -0.0036 -0.0020 -0.0022 0.0037 0.0015 0.0025 0.0005 -0.0027 -0.0020 0.0015 0.0007 0.0075 -0.0037 0.0012 0.0096 0.0012 0.0042 0.0066 0.0070 0.0045 0.0093 0.0060 0.0058 0.0089 0.0099 0.0061 0.0035 -0.0019 0.0030 0.0097 0.0071 0.0058 0.0006 0.0014 0.0004 -0.0036 -0.0007 -0.0022 -0.0015 0.0021 0.0043 0.0020 0.0008 0.0012 0.0003 0.0005 -0.0017 0.0022 -0.0026 -0.0071

-0.0045 -0.0003 -0.0078 -0.0058 -0.0062 -0.0095 -0.0065 -0.0059 -0.0084 -0.0069 -0.0138
-0.0067 -0.0093 -0.0060 -0.0087 -0.0054 -0.0083 -0.0084 -0.0081 -0.0023 -0.0046 - 0.0107
-0.0131 -0.0098 -0.0066 -0.0103 -0.0113 -0.0126 -0.0142 -0.0132 -0.0084 -0.0032 -0.0080
-0.0081 -0.0062 -0.0114 -0.0038 -0.0078 -0.0058 -0.0015 -0.0116 -0.0045 -0.0079 -0.0081
- 0.0163 -0.0081 -0.0074 -0.0086 -0.0026 -0.0070 -0.0051 -0.0094 -0.0040 -0.0019 0.0006
0.0059 0.0048 0.0060 0.0053 0.0059 0.0016 0.0051 0.0058 0.0052 0.0011 -0.0002 0.0007
0.0094 0.0079 0.0112 0.0100 0.0065 0.0080 0.0096 0.0111 0.0117 0.0101 0.0157 0.0157
0.0150 0.0127 0.0132 0.0118 0.0097 0.0103 0.0103 0.0124 0.0148 0.0107 0.0038 0.0068
0.0072 0.0105 0.0126 0.0122 0.0135 0.0134 0.0082 0.0063 0.0021 -0.0009 -0.0026 0.0024
0.0010 0.0027 0.0041 0.0048 0.0058 0.0047 0.0060 0.0026 0.0057 0.0029 0.0043 0.0049
-0.0001 0.0019 -0.0033 -0.0066 -0.0055 - 0.0148 -0.0111 -0.0129 -0.0131 -0.0132 -0.0128
-0.0103 -0.0114 -0.0111 -0.0107 -0.0149 -0.0136 -0.0110 -0.0184 -0.0209 -0.0199 -0.0172
-0.0141 -0.0146 -0.0154 -0.0169 -0.0186 -0.0220 -0.0178 -0.0141 -0.0220 -0.0198 -0.0178
-0.0195 -0.0187 -0.0185 -0.0175 -0.0161 -0.0186 -0.0189 -0.0165 -0.0152 -0.0093 -0.0086
-0.0075 -0.0096 -0.0054 -0.0087 -0.0042 -0.0041 -0.0005 0.0001 0.0007 -0.0024 0.0010
0.0053 0.0065 0.0114 0.0103 0.0123 0.0154 0.0152 0.0212 0.0211 0.0244 0.0233 0.0263
0.0337 0.0332 0.0374 0.0510 0.0512 0.0663 0.0700 0.0799 0.0943 0.1176 0.1433 0.2099
0.6937 0.2099 0.1433 0.1176 0.0943 0.0799 0.0700 0.0663 0.0512 0.0510 0.0374 0.0332
0.0337 0.0263 0.0233 0.0244 0.0211 0.0212 0.0152 0.0154 0.0123 0.0103 0.0114 0.0065
0.0053 0.0010 -0.0024 0.0007 0.0001 -0.0005 -0.0041 -0.0042 -0.0087 -0.0054 -0.0096 -
0.0075 -0.0086 - 0.0093 -0.0152 -0.0165 -0.0189 -0.0186 -0.0161 -0.0175 -0.0185 -0.0187
-0.0195 -0.0178 -0.0198 -0.0220 -0.0141 -0.0178 -0.0220 -0.0186 -0.0169 -0.0154 -0.0146
-0.0141 -0.0172 -0.0199 - 0.0209 -0.0184 -0.0110 -0.0136 -0.0149 -0.0107 -0.0111 -0.0114
-0.0103 -0.0128 -0.0132 -0.0131 -0.0129 -0.0111 -0.0148 -0.0055 -0.0066 -0.0033 0.0019
-0.0001 0.0049 0.0043 0.0029 0.0057 0.0026 0.0060 0.0047 0.0058 0.0048 0.0041 0.0027
0.0010 0.0024 -0.0026 -0.0009 0.0021 0.0063 0.0082 0.0134 0.0135 0.0122 0.0126 0.0105
0.0072 0.0068 0.0038 0.0107 0.0148 0.0124 0.0103 0.0103 0.0097 0.0118 0.0132 0.0127
0.0150 0.0157 0.0157 0.0101 0.0117 0.0111 0.0096 0.0080 0.0065 0.0100 0.0112 0.0079
0.0094 0.0007 -0.0002 0.0011 0.0052 0.0058 0.0051 0.0016 0.0059 0.0053 0.0060 0.0048
0.0059 0.0006 -0.0019 -0.0040 -0.0094 -0.0051 -0.0070 -0.0026 -0.0086 -0.0074 -0.0081
-0.0163 -0.0081 -0.0079 -0.0045 -0.0116 -0.0015 -0.0058 -0.0078 -0.0038 - 0.0114 -0.0062

-0.0081 -0.0080 -0.0032 -0.0084 -0.0132 -0.0142 -0.0126 -0.0113 -0.0103 -0.0066 -0.0098 -0.0131 -0.0107 -0.0046 -0.0023 -0.0081 -0.0084 -0.0083 -0.0054 -0.0087 -0.0060 -0.0093 -0.0067 -0.0138 -0.0069 -0.0084 -0.0059 -0.0065 -0.0095 -0.0062 -0.0058 -0.0078 -0.0003 -0.0045 -0.0071 -0.0026 0.0022 -0.0017 0.0005 0.0003 0.0012 0.0008 0.0020 0.0043 0.0021 - 0.0015 -0.0022 -0.0007 -0.0036 0.0004 0.0014 0.0006 0.0058 0.0071 0.0097 0.0030 - 0.0019 0.0035 0.0061 0.0099 0.0089 0.0058 0.0060 0.0093 0.0045 0.0070 0.0066 0.0042 0.0012 0.0096 0.0012 -0.0037 0.0075 0.0007 0.0015 -0.0020 -0.0027 0.0005 0.0025 0.0015 0.0037 -0.0022 - 0.0020 -0.0036 -0.0028 -0.0091 -0.0042 -0.0098 -0.0118 -0.0059 -0.0057 -0.0072 -0.0060 -0.0098 -0.0146 -0.0127 -0.0101 -0.0106 -0.0120 -0.0121 -0.0122 -0.0144 -0.0079 -0.0103 -0.0093 - 0.0098 -0.0114 -0.0099 -0.0042 -0.0069 -0.0031 -0.0082 -0.0071 -0.0046 -0.0020 -0.0064 -0.0018 -0.0027 -0.0024 -0.0012 -0.0030 -0.0019 -0.0012 -0.0058 -0.0018 -0.0038 -0.0008 -0.0010 0.0023 0.0016 0.0040 0.0023 0.0015 -0.0031 -0.0007 0.0023 -0.0009 -0.0033 -0.0014 0.0010 0.0013 0.0033 0.0028 0.0020 0.0019 0.0069 0.0043 0.0191 0.0025 0.0011 0.0033 -0.0007 0.0017 - 0.0022 0.0009 -0.0040 0.0018 -0.0025 - 0.0004 -0.0003 0.0003 0.0029 0.0007 0.0006 0.0007 -0.0013 0.0048 -0.0029 0.0003 -0.0003 0.0013 0.0032 0.0010 -0.0013 -0.0029 0.0011 0.0020 0.0002 0.0020 0.0001 0.0112 0.0053 0.0044 0.0075 0.0120 0.0117 0.0084 0.0082 0.0101 0.0055 0.0100 0.0086 0.0080 0.0100 0.0099 0.0100 0.0066 0.0013 0.0074 0.0024 0.0052 -0.0032 -0.0032 -0.0005 0.0023 - 0.0030 -0.0003 -0.0074 -0.0079 -0.0098 -0.0053 -0.0095 -0.0103 -0.0148 -0.0121 -0.0138 -0.0075 -0.0045 0.0006 -0.0126 -0.0070 -0.0074 -0.0045 -0.0192 -0.0095 0.0002 -0.0057 -0.0053 -0.0027 -0.0060 -0.0060 -0.0042 -0.0031 -0.0012 -0.0025 -0.0015 -0.0078 -0.0037 - 0.0035 -0.0015 -0.0042 -0.0009 -0.0062 -0.0014 -0.0026 -0.0037 -0.0028 -0.0061 -0.0016 0.0004 -0.0017 -0.0055 -0.0064 -0.0020 -0.0012 -0.0028 -0.0057 -0.0079 -0.0062 -0.0004 -0.0013 0.0019 0.0026 0.0043 0.0011 0.0001 0.0000 0.0018 0.0024 -0.0005 0.0037 0.0027 0.0047 0.0076 0.0026 -0.0009 0.0022 0.0057 0.0094 0.0028 0.0025 0.0018 0.0099 0.0092 0.0077 0.0035 0.0082 0.0060 0.0044 0.0082 0.0080 0.0078 0.0157 0.0096 0.0108 0.0132 0.0194 0.0138 0.0202 0.0201 0.0217 -0.3372.

Appendix C

30 KM/HR CHANNEL FIR FILTER CONSTANTS

The numbers is written below, exhibits the 30 km/hr wireless channel by using Parks-McClellan optimal equiripple 925 linear phase FIR filter coefficients:-0.3088 0.0210 0.0109 -0.0005 -0.0030 -0.0035 -0.0074 -0.0034 -0.0044 0.0085 0.0102 0.0056 0.0027 -0.0010 -0.0008 -0.0013 -0.0073 -0.0031 -0.0040 0.0026 0.0018 -0.0014 -0.0014 0.0031 0.0046 0.0002 -0.0015 -0.0040 -0.0020 0.0067 0.0009 0.0040 -0.0025 -0.0022 0.0020 0.0041 0.0011 -0.0036 0.0065 0.0058 0.0033 0.0093 0.0090 0.0049 -0.0018 -0.0008 -0.0018 -0.0077 -0.0089 -0.0117 -0.0091 -0.0059 -0.0014 0.0031 -0.0033 0.0016 0.0005 -0.0019 -0.0016 0.0026 0.0081 0.0077 0.0085 0.0078 0.0125 0.0086 0.0012 0.0034 -0.0015 0.0004 -0.0019 -0.0056 - 0.0027 -0.0033 0.0079 0.0004 0.0154 -0.0022 -0.0154 -0.0010 -0.0093 -0.0114 -0.0144 -0.0105 -0.0084 -0.0062 0.0002 0.0097 0.0038 0.0026 -0.0026 -0.0001 -0.0031 0.0044 -0.0013 -0.0039 -0.0076 0.0005 0.0030 0.0024 -0.0017 0.0047 -0.0015 -0.0012 0.0001 -0.0013 0.0001 -0.0003 -0.0025 -0.0006 0.0007 -0.0003 -0.0101 -0.0116 -0.0074 -0.0030 -0.0016 0.0058 0.0025 0.0099 0.0071 -0.0018 -0.0038 0.0003 0.0018 -0.0081 -0.0028 0.0063 0.0067 0.0090 0.0050 0.0025 0.0013 0.0015 -0.0060 -0.0040 -0.0036 -0.0053 -0.0011 0.0066 0.0054 -0.0005 0.0021 0.0007 0.0056 0.0000 -0.0075 -0.0060 -0.0065 -0.0055 -0.0094 -0.0087 -0.0051 -0.0011 0.0090 -0.0026 -0.0019 -0.0024 -0.0016 -0.0038 0.0018 0.0043 0.0052 -0.0011 -0.0002 0.0018 -0.0024 -0.0046 -0.0038 0.0010 0.0039 0.0049 0.0036 0.0010 0.0002 0.0020 -0.0018 0.0014 0.0025 -0.0008 0.0032 0.0017 -0.0004 -0.0048 -0.0021 -0.0056 -0.0068 -0.0055 -0.0070 -0.0018 -0.0005 0.0029 -0.0011 0.0076 0.0059 0.0093 0.0030 -0.0012 -0.0039 -0.0014 -0.0034 -0.0036 -0.0074 0.0025 0.0052 0.0054 0.0064 0.0023 -0.0022 -0.0057 -0.0087 0.0007 0.0007 0.0028 0.0008 -0.0034 0.0049 -0.0016 -0.0098 -0.0025 0.0044 0.0025 0.0021 0.0056 0.0043 0.0065 0.0043 0.0036 - 0.0082 0.0009 -0.0035 0.0080 0.0038 -0.0005 -0.0000 0.0019 0.0033 -0.0014 0.0004 -0.0041 -0.0003 0.0001 -0.0017 -0.0012 -0.0015 0.0004 0.0021 0.0056 0.0070 0.0036 -0.0056 -0.0012 -0.0096 -0.0060 -0.0060 0.0094 0.0040 0.0034 0.0046

0.0059 0.0025 -0.0021 -0.0041 -0.0042 -0.0032 0.0028 0.0021 0.0069 0.0063 0.0024 0.0020
0.0031 -0.0032 -0.0024 0.0048 -0.0020 -0.0076 -0.0026 0.0010 0.0057 0.0052 -0.0016
0.0021 -0.0029 -0.0008 0.0085 0.0024 0.0064 -0.0017 -0.0046 0.0007 0.0027 0.0001 -
0.0042 -0.0056 -0.0022 -0.0058 -0.0034 0.0052 0.0048 0.0077 0.0062 -0.0016 -0.0045
-0.0075 -0.0071 -0.0067 -0.0024 -0.0075 0.0007 0.0030 0.0059 0.0040 -0.0022 -0.0022
-0.0005 -0.0082 -0.0083 -0.0102 0.0001 0.0030 0.0050 0.0071 0.0016 0.0003 -0.0049 -
0.0058 0.0002 -0.0023 0.0014 0.0017 0.0069 0.0062 0.0125 0.0063 0.0051 0.0001 -0.0044
-0.0138 -0.0104 -0.0003 0.0030 0.0075 0.0106 0.0042 0.0032 0.0076 -0.0024 -0.0047
-0.0074 -0.0098 -0.0058 -0.0031 0.0016 0.0080 0.0093 0.0024 0.0023 -0.0011 -0.0032
-0.0031 0.0008 0.0013 0.0062 0.0042 0.0126 0.0017 -0.0009 -0.0059 -0.0053 -0.0067
-0.0035 0.0035 0.0085 0.0095 0.0100 0.0100 0.0017 0.0002 -0.0045 -0.0169 -0.0040 -
0.0093 -0.0027 0.0057 0.0018 0.0045 0.0080 0.0041 0.0053 -0.0068 -0.0016 -0.0055 -
0.0027 -0.0004 0.0017 0.0105 0.0083 0.0117 0.0094 0.0038 0.0017 -0.0064 -0.0086 -
0.0080 -0.0010 0.0085 0.0239 0.0186 0.0146 0.0064 -0.0044 -0.0076 -0.0105 -0.0154
-0.0031 -0.0032 0.0144 0.0129 0.0130 0.0096 0.0060 -0.0052 -0.0119 -0.0140 -0.0070
-0.0056 0.0051 0.0145 0.0157 0.0230 0.0229 0.0070 -0.0051 -0.0178 -0.0219 -0.0131
-0.0064 0.0059 0.0162 0.0195 0.0221 0.0145 0.0031 -0.0116 -0.0158 -0.0242 -0.0197
-0.0135 0.0076 0.0279 0.0346 0.0311 0.0158 -0.0079 -0.0305 -0.0545 -0.0600 -0.0458
-0.0004 0.0739 0.2022 0.8063 0.2022 0.0739 -0.0004 -0.0458 -0.0600 -0.0545 -0.0305
-0.0079 0.0158 0.0311 0.0346 0.0279 0.0076 -0.0135 -0.0197 -0.0242 -0.0158 -0.0116
0.0031 0.0145 0.0221 0.0195 0.0162 0.0059 -0.0064 -0.0131 -0.0219 -0.0178 -0.0051
0.0070 0.0229 0.0230 0.0157 0.0145 0.0051 -0.0056 -0.0070 -0.0140 -0.0119 -0.0052
0.0060 0.0096 0.0130 0.0129 0.0144 -0.0032 -0.0031 -0.0154 -0.0105 -0.0076 -0.0044
0.0064 0.0146 0.0186 0.0239 0.0085 -0.0010 -0.0080 -0.0086 -0.0064 0.0017 0.0038 0.0094
0.0117 0.0083 0.0105 0.0017 -0.0004 -0.0027 -0.0055 -0.0016 -0.0068 0.0053 0.0041
0.0080 0.0045 0.0018 0.0057 -0.0027 -0.0093 -0.0040 -0.0169 -0.0045 0.0002 0.0017
0.0100 0.0100 0.0095 0.0085 0.0035 -0.0035 -0.0067 -0.0053 -0.0059 -0.0009 0.0017
0.0126 0.0042 0.0062 0.0013 0.0008 -0.0031 -0.0032 -0.0011 0.0023 0.0024 0.0093 0.0080
0.0016 -0.0031 -0.0058 -0.0098 -0.0074 -0.0047 -0.0024 0.0076 0.0032 0.0042 0.0106
0.0075 0.0030 -0.0003 -0.0104 -0.0138 -0.0044 0.0001 0.0051 0.0063 0.0125 0.0062 0.0069
0.0017 0.0014 -0.0023 0.0002 -0.0058 -0.0049 0.0003 0.0016 0.0071 0.0050 0.0030 0.0001

-0.0102 -0.0083 -0.0082 -0.0005 -0.0022 -0.0022 0.0040 0.0059 0.0030 0.0007 -0.0075 -0.0024 -0.0067 -0.0071 -0.0075 -0.0045 -0.0016 0.0062 0.0077 0.0048 0.0052 -0.0034 -0.0058 -0.0022 -0.0056 -0.0042 0.0001 0.0027 0.0007 -0.0046 -0.0017 0.0064 0.0024 0.0085 -0.0008 -0.0029 0.0021 -0.0016 0.0052 0.0057 0.0010 -0.0026 -0.0076 -0.0020 0.0048 -0.0024 -0.0032 0.0031 0.0020 0.0024 0.0063 0.0069 0.0021 0.0028 -0.0032 -0.0042 -0.0041 -0.0021 0.0025 0.0059 0.0046 0.0034 0.0040 0.0094 -0.0060 -0.0060 -0.0096 -0.0012 -0.0056 0.0036 0.0070 0.0056 0.0021 0.0004 -0.0015 -0.0012 -0.0017 0.0001 -0.0003 -0.0041 0.0004 -0.0014 0.0033 0.0019 -0.0000 -0.0005 0.0038 0.0080 -0.0035 0.0009 -0.0082 0.0036 0.0043 0.0065 0.0043 0.0056 0.0021 0.0025 0.0044 -0.0025 -0.0098 -0.0016 0.0049 -0.0034 0.0008 0.0028 0.0007 0.0007 -0.0087 -0.0057 -0.0022 0.0023 0.0064 0.0054 0.0052 0.0025 -0.0074 -0.0036 -0.0034 -0.0014 -0.0039 -0.0012 0.0030 0.0093 0.0059 0.0076 - 0.0011 0.0029 -0.0005 -0.0018 -0.0070 -0.0055 -0.0068 -0.0056 -0.0021 -0.0048 -0.0004 0.0017 0.0032 -0.0008 0.0025 0.0014 -0.0018 0.0020 0.0002 0.0010 0.0036 0.0049 0.0039 0.0010 - 0.0038 -0.0046 -0.0024 0.0018 -0.0002 -0.0011 0.0052 0.0043 0.0018 -0.0038 -0.0016 -0.0024 -0.0019 -0.0026 0.0090 -0.0011 -0.0051 -0.0087 -0.0094 -0.0055 -0.0065 -0.0060 -0.0075 0.0000 0.0056 0.0007 0.0021 -0.0005 0.0054 0.0066 -0.0011 -0.0053 -0.0036 -0.0040 -0.0060 0.0015 0.0013 0.0025 0.0050 0.0090 0.0067 0.0063 -0.0028 -0.0081 0.0018 0.0003 -0.0038 -0.0018 0.0071 0.0099 0.0025 0.0058 -0.0016 -0.0030 -0.0074 -0.0116 -0.0101 -0.0003 0.0007 -0.0006 -0.0025 -0.0003 0.0001 -0.0013 0.0001 -0.0012 -0.0015 0.0047 -0.0017 0.0024 0.0030 0.0005 -0.0076 -0.0039 -0.0013 0.0044 -0.0031 -0.0001 -0.0026 0.0026 0.0038 0.0097 0.0002 -0.0062 -0.0084 -0.0105 -0.0144 -0.0114 -0.0093 -0.0010 -0.0154 -0.0022 0.0154 0.0004 0.0079 -0.0033 -0.0027 -0.0056 -0.0019 0.0004 -0.0015 0.0034 0.0012 0.0086 0.0125 0.0078 0.0085 0.0077 0.0081 0.0026 -0.0016 -0.0019 0.0005 0.0016 -0.0033 0.0031 -0.0014 -0.0059 -0.0091 -0.0117 -0.0089 -0.0077 -0.0018 -0.0008 -0.0018 0.0049 0.0090 0.0093 0.0033 0.0058 0.0065 -0.0036 0.0011 0.0041 0.0020 -0.0022 -0.0025 0.0040 0.0009 0.0067 -0.0020 -0.0040 -0.0015 0.0002 0.0046 0.0031 -0.0014 -0.0014 0.0018 0.0026 -0.0040 -0.0031 -0.0073 -0.0013 -0.0008 -0.0010 0.0027 0.0056 0.0102 0.0085 -0.0044 -0.0034 -0.0074 -0.0035 -0.0030 -0.0005 0.0109 0.0210 -0.3088.

Appendix D

100 KM/HR CHANNEL FIR FILTER CONSTANTS

Presented numbers here demonstrates the 100 km/hr wireless channel via Parks-McClellan optimal equiripple 513 linear phase FIR filter coefficients: 0.2426 0.3187 -0.1774 0.0912 -0.0509 0.0324 -0.0187 0.0108 -0.0048 0.0054 -0.0006 -0.0014 0.0040 -0.0025 -0.0016 0.0021 0.0004 -0.0028 0.0006 -0.0072 0.0046 0.0008 -0.0088 0.0001 -0.0055 0.0047 -0.0017 -0.0007 -0.0052 0.0001 -0.0038 0.0038 -0.0014 -0.0013 -0.0087 -0.0066 0.0094 0.0006 -0.0017 0.0007 0.0038 -0.0036 -0.0082 0.0064 -0.0043 -0.0048 0.0036 0.0010 -0.0045 0.0054 0.0059 -0.0052 0.0009 0.0054 -0.0066 -0.0088 0.0032 0.0082 -0.0048 -0.0062 -0.0028 0.0033 -0.0044 -0.0001 -0.0081 -0.0058 -0.0053 0.0010 -0.0057 0.0072 0.0009 -0.0079 0.0023 0.0078 -0.0032 -0.0033 -0.0025 0.0009 -0.0078 -0.0017 -0.0063 -0.0044 0.0040 -0.0084 -0.0045 -0.0001 -0.0082 0.0021 -0.0051 0.0031 0.0003 0.0045 0.0055 -0.0029 -0.0098 -0.0050 0.0013 0.0053 -0.0030 -0.0084 0.0031 -0.0056 -0.0084 -0.0054 -0.0038 -0.0059 -0.0072 0.0029 -0.0010 -0.0020 0.0002 -0.0029 -0.0097 0.0100 0.0054 -0.0055 -0.0014 0.0070 -0.0080 -0.0075 0.0077 -0.0012 -0.0098 0.0017 -0.0023 -0.0065 0.0025 0.0071 -0.0061 -0.0071 0.0030 0.0014 -0.0100 0.0013 -0.0069 -0.0030 -0.0054 -0.0009 -0.0032 0.0031 -0.0042 0.0025 0.0021 -0.0012 -0.0018 -0.0003 0.0000 -0.0033 -0.0012 0.0010 0.0008 0.0026 -0.0017 0.0003 0.0040 -0.0015 0.0081 0.0056 -0.0029 -0.0012 -0.0046 -0.0003 0.0011 0.0030 -0.0022 -0.0064 -0.0039 -0.0067 -0.0012 0.0061 0.0099 -0.0038 -0.0023 -0.0009 -0.0025 0.0028 -0.0019 -0.0017 -0.0019 0.0032 -0.0061 -0.0054 -0.0002 -0.0016 -0.0012 -0.0022 -0.0059 -0.0052 -0.0008 0.0070 -0.0077 -0.0011 -0.0013 -0.0122 0.0005 0.0043 -0.0111 0.0026 0.0080 -0.0057 -0.0009 0.0040 -0.0093 -0.0056 0.0072 0.0067 -0.0119 0.0038 0.0131 -0.0116 -0.0043 -0.0045 -0.0116 0.0039 0.0040 0.0009 -0.0031 0.0057 -0.0055 -0.0028 0.0108 0.0084 -0.0034 0.0029 0.0064 -0.0056 -0.0083 0.0050 -0.0038 -0.0084 0.0085 0.0012 -0.0164 0.0115 0.0007 -0.0182 -0.0002 0.0098 -0.0121 0.0063 0.0202 -0.0060 -0.0075 0.0232 -0.0090 -0.0207 0.0184 0.0016 -0.0222 0.0209 0.0132 -0.0386 0.0094 0.0441 -0.0802 0.0322 0.7410 0.0322 -

0.0802 0.0441 0.0094 -0.0386 0.0132 0.0209 - 0.0222 0.0016 0.0184 -0.0207 -0.0090 0.0232 -0.0075 -0.0060 0.0202 0.0063 -0.0121 0.0098 -0.0002 -0.0182 0.0007 0.0115 -0.0164 0.0012 0.0085 -0.0084 -0.0038 0.0050 -0.0083 -0.0056 0.0064 0.0029 -0.0034 0.0084 0.0108 -0.0028 -0.0055 0.0057 -0.0031 0.0009 0.0040 0.0039 -0.0116 -0.0045 -0.0043 -0.0116 0.0131 0.0038 -0.0119 0.0067 0.0072 -0.0056 -0.0093 0.0040 -0.0009 -0.0057 0.0080 0.0026 -0.0111 0.0043 0.0005 -0.0122 -0.0013 -0.0011 -0.0077 0.0070 - 0.0008 -0.0052 -0.0059 -0.0022 -0.0012 -0.0016 -0.0002 -0.0054 -0.0061 0.0032 -0.0019 -0.0017 -0.0019 0.0028 -0.0025 -0.0009 -0.0023 -0.0038 0.0099 0.0061 -0.0012 -0.0067 -0.0039 -0.0064 -0.0022 0.0030 0.0011 -0.0003 -0.0046 -0.0012 -0.0029 0.0056 0.0081 -0.0015 0.0040 0.0003 -0.0017 0.0026 0.0008 0.0010 -0.0012 -0.0033 0.0000 -0.0003 - 0.0018 -0.0012 0.0021 0.0025 -0.0042 0.0031 -0.0032 -0.0009 -0.0054 -0.0030 -0.0069 0.0013 -0.0100 0.0014 0.0030 -0.0071 -0.0061 0.0071 0.0025 -0.0065 -0.0023 0.0017 - 0.0098 -0.0012 0.0077 -0.0075 -0.0080 0.0070 -0.0014 -0.0055 0.0054 0.0100 -0.0097 -0.0029 0.0002 -0.0020 -0.0010 0.0029 -0.0072 -0.0059 -0.0038 -0.0054 -0.0084 -0.0056 0.0031 -0.0084 -0.0030 0.0053 0.0013 -0.0050 -0.0098 -0.0029 0.0055 0.0045 0.0003 0.0031 -0.0051 0.0021 -0.0082 -0.0001 -0.0045 -0.0084 0.0040 -0.0044 -0.0063 -0.0017 -0.0078 0.0009 -0.0025 -0.0033 -0.0032 0.0078 0.0023 -0.0079 0.0009 0.0072 -0.0057 0.0010 -0.0053 -0.0058 -0.0081 -0.0001 -0.0044 0.0033 -0.0028 -0.0062 -0.0048 0.0082 0.0032 -0.0088 -0.0066 0.0054 0.0009 -0.0052 0.0059 0.0054 -0.0045 0.0010 0.0036 - 0.0048 -0.0043 0.0064 -0.0082 -0.0036 0.0038 0.0007 -0.0017 0.0006 0.0094 -0.0066 -0.0087 -0.0013 -0.0014 0.0038 -0.0038 0.0001 -0.0052 -0.0007 -0.0017 0.0047 -0.0055 0.0001 -0.0088 0.0008 0.0046 -0.0072 0.0006 -0.0028 0.0004 0.0021 -0.0016 -0.0025 0.0040 -0.0014 -0.0006 0.0054 -0.0048 0.0108 -0.0187 0.0324 -0.0509 0.0912 -0.1774 0.3187 0.2426.

Appendix E

MATLAB M-FILES

This appendix includes a description of the M-files that were written specially for this thesis. All of the M-files written for this thesis is available at the following URL: http://www.geocities.com/alieksim/Thesis_Mfiles.zip

cdf_cellular.m

It calculates cdf of C/I with using Walfish Ikegami COST231 Model in the cellular environment where the 4000 users uniformly distributed.

cdf_wlan500m.m

It calculates cdf of C/I with using Walfish Ikegami COST231 Model in the HOT-SPOT where the center is at 500m.

cdf_wlan50m.m

It calculates cdf of C/I with using Walfish Ikegami COST231 Model in the HOT-SPOT where the center is at 50m.

cdf_wlan750m.m

It calculates cdf of C/I with using Walfish Ikegami COST231 Model in the HOT-SPOT where the center is at 750m.

cdf_wlan950m.m

It calculates cdf of C/I with using Walfish Ikegami COST231 Model in the HOT-SPOT where the center is at 950m.

Mcast_Nof_users_vs_thro_lat_100kmh_3slotdelay.m

It calculates the 3 slot delay Multicast scheduling performances of IS-856 system in 100-km/hr channel.

Mcast_Nof_users_vs_thro_lat_100kmh_inst.m

It calculates the instantaneous Multicast scheduling performances of IS-856 system in 100-km/hr channel.

Mcast_Nof_users_vs_thro_lat_30kmh_3slotdelay.m

It calculates the 3 slot delay Multicast scheduling performances of IS-856 system in 30-km/hr channel.

Mcast_Nof_user_vs_thro_lat_30kmh_inst.m

It calculates the instantaneous Multicast scheduling performances of IS-856 system in 30-km/hr channel.

Mcast_Nof_users_vs_thro_lat_3kmh_3slotdelay.m

It calculates the 3 slot delay Multicast scheduling performances of IS-856 system in 3-km/hr channel.

Mcast_Nof_user_vs_thro_lat_3kmh_inst.m

It calculates the instantaneous Multicast scheduling performances of IS-856 system in 3-km/hr channel.

Mserv_Nof_users_vs_thro_lat_100kmh_3slotdelay.m

It calculates the 3 slot delay Multi-Service scheduling performances of IS-856 system in 100-km/hr channel.

Mserv_Nof_users_vs_thro_lat_100kmh_instant.m

It calculates the instantaneous Multi-Service scheduling performances of IS-856 system in 100-km/hr channel.

Mserv_Nof_users_vs_thro_lat_30kmh_3slotdelay.m

It calculates the 3 slot delay Multi-Service scheduling performances of IS-856 system in 30-km/hr channel.

Mserv_Nof_users_vs_thro_lat_30kmh_instant.m

It calculates the instantaneous Multi-Service scheduling performances of IS-856 system in 30-km/hr channel.

Mserv_Nof_users_vs_thro_lat_3kmh_3slotdelay.m

It calculates the 3 slot delay Multi-Service scheduling performances of IS-856 system in 3-km/hr channel.

Mserv_Nof_users_vs_thro_lat_3kmh_instant.m

It calculates the instantaneous Multi-Service scheduling performances of IS-856 system in 3-km/hr channel.

Number_of_users_vs_thro_lat_100kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of IS-856 system in 100-km/hr channel.

Number_of_users_vs_thro_lat_100kmh_instan.m

It calculates the instantaneous scheduling performances of IS-856 system in 100-km/hr channel.

Number_of_users_vs_thro_lat_30kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of IS-856 system in 30-km/hr channel.

Number_of_users_vs_thro_lat_30kmh_instan.m

It calculates the instantaneous scheduling performances of IS-856 system in 30-km/hr channel.

Number_of_users_vs_thro_lat_3kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of IS-856 system in 3-km/hr channel.

Number_of_users_vs_thro_lat_3kmh_instan.m

It calculates the instantaneous scheduling performances of IS-856 system in 3-km/hr channel.

Two_users_vs_thro_lat_100kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of proposed two users at a time system in 100-km/hr channel.

Two_users_vs_thro_lat_100kmh_instan.m

It calculates the instantaneous scheduling performances of proposed two users at a time system in 100-km/hr channel.

Two_users_vs_thro_lat_30kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of proposed two users at a time system in 30-km/hr channel.

Two_users_vs_thro_lat_30kmh_instan.m

It calculates the instantaneous scheduling performances of proposed two users at a time system in 30-km/hr channel.

Two_users_vs_thro_lat_3kmh_3slotdelay.m

It calculates the 3 slot delay scheduling performances of proposed two users at a time system in 3-km/hr channel.

Two_users_vs_thro_lat_3kmh_instan.m

It calculates the instantaneous scheduling performances of proposed two users at a time system in 3-km/hr channel.

Window_size_vs_thro_lat_10user.m

It calculates 3 slot delay scheduling performances of IS-856 system with 10 users in 3-km/h channel, 10 users in 30-km/h channel and 10 users in 100-km/h channel.

Window_size_vs_thro_lat_10user_insta.m

It calculates instantaneous scheduling performances of IS-856 system with 10 users in 3-km/h channel, 10 users in 30-km/h channel and 10 users in 100-km/h channel.

Window_size_vs_thro_lat_20user.m

It calculates 3 slot delay scheduling performances of IS-856 system with 20 users in 3-km/h channel, 20 users in 30-km/h channel and 20 users in 100-km/h channel.

Window_size_vs_thro_lat_20user_insta.m

It calculates instantaneous scheduling performances of IS-856 system with 10 users in 3-km/h channel, 10 users in 30-km/h channel and 10 users in 100-km/h channel.

Wlan500m_2usr_nofusr_vs_thro_lat_100km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_2usr_nofusr_vs_thro_lat_30km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_2usr_nofusr_vs_thro_lat_3km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_100km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_100km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_30km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_30km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_3km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan500m_nofusr_vs_thro_lat_3km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 500 m.

Wlan50m_2usr_nofusr_vs_thro_lat_100km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_2usr_nofusr_vs_thro_lat_30km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_2usr_nofusr_vs_thro_lat_3km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_100km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_100km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_30km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_30km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_3km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan50m_nofusr_vs_thro_lat_3km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 50 m.

Wlan750m_2usr_nofusr_vs_thro_lat_100km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_2usr_nofusr_vs_thro_lat_30km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_2usr_nofusr_vs_thro_lat_3km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_100km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_100km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_30km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_30km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_3km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan750m_nofusr_vs_thro_lat_3km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 750 m.

Wlan950m_2usr_nofusr_vs_thro_lat_100km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_2usr_nofusr_vs_thro_lat_30km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_2usr_nofusr_vs_thro_lat_3km_3slot_dly.m

It calculates 3 slot delay scheduling performances of two users at a time system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_100km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_100km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 100-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_30km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_30km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 30-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_3km_3slot.m

It calculates 3 slot delay scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

Wlan950m_nofusr_vs_thro_lat_3km_instant.m

It calculates instantaneous scheduling performances of IS-856 system with 3-km/hr channel that 50% of the users present in the cellular environment. The rest of the users attend in the HOT-SPOT with a 0.5-km/hr channel. The Hot-Spot center is placed at 950 m.

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