POWER BASED SCHEDULING ALGORITHMS FOR WCDMA NETWORKS

BY

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عمادة الدراسات العليا
DEANSHIP OF GRADUATE STUDIES

Dedicated to My Parents & My Sister

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LIST OF ABBREVIATIONS

CDMA	Code Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
TDMA	Time Division Multiple Access
FDMA	Frequency Division Multiple Access
QOS	Quality of Service
SLA	Service Level Agreement
WWW	World Wide Web
3G	Third Generation
4G	Fourth Generation
3GPP	Third Generation Partnership Project
UMTS	Universal Mobile Telecommunications System
ITU	International Telecommunication Union
IMT-2000	International Mobile Telecommunications 2000
BS	Base Station
FDD	Frequency Division Duplex
TDD	Time Division Duplex
BER	Bit Error Rate
Kbps	Kilobits per second
ms	millisecond
Mbps	Mega bits per second

MHz	Mega Hertz
CDF	Cumulative Distribution Function
EDF	Earliest Deadline First Algorithm
PEDF	Powered Earliest Deadline First Algorithm
MinPower EDF	Minimum Power Earliest Deadline First Algorithm
MinPower PEDF	Minimum Power Powered Earliest Deadline First Algorithm
MaxPower EDF	Maximum Power Earliest Deadline First Algorithm
MaxPower PEDF	Maximum Power Powered Earliest Deadline First Algorithm

THESIS ABSTRACT (English)

Name: Mohammed Yousuf Shareef

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With the advent of huge expansion of wireless and wired internet-based network, the network operators as well as network designers are working hard to accommodate the services emerged of this expected seamless networks. These services are calling for a network that can differentiate and satisfy the QoS requirements of each user. It is obvious that this task is very challenging one and this work has addressed the issue of QoS provisioning over the wireless network through designing an adaptive scheduling scheme. The literature is rich with proposals that are suggested to achieve the above objectives. In this work, a scheduler is devised that can efficiently share the resources among the admitted users by guaranteeing QoS. It is based on scheduling the resources based on power requirements to all users. Further, it is associated with EDF-based scheduler that is known for its minimum delay performance. Several versions have been proposed, namely MinPower EDF, MaxPower EDF, MinPower PEDF, MaxPower PEDF.

Extensive simulation runs have been conducted assuming a 19-cell CDMA network layout. The results show an outstanding performance in terms of throughput and packet *delay especially for low and moderate loads. More, the loss probability is found to be very low compared to original EDF and PEDF. There is 25% decrease in loss probability compared to EDF and PEDF and there is 70-80% decrease in packet delay compared to EDF and PEDF. Using Jain's fairness index, we have studied the fairness of each proposal and compared with EDF and PEDF. Finally, the study shows the high sensitivity of scheduling interval.*

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THESIS ABSTRACT (Arabic)

الإسم : محمد يوسف شريف
عنوان الرسالة : نظم الجدولة المعتمدة على الطاقة في الشبكات اللاسلكية (*WCDMA Networks*)
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مع التوسع الهائل في استخدام الشبكات السلكية و اللاسلكية في خدمات الشبكات , مصمموا هذه الشبكات بالاضافة الى العاملين عليها يعملون بجهد لمواكبة الخدمات التي من المتوقع ان تظهر مع هذا التوسع الهائل و الذي لا نهاية له. هذه الخدمات تتطلب شبكة تستطيع التعامل مع متطلبات كل مستخدم .و من الواضح أن هذه المهمة تمثل تحدياً كبيراً خصوصاً و أننا نحتاج الى توفير خدمة نوعبة تلائم حاجات كل زبون على حدة, و لذلك وجب علينا اعداد خطط مجدولة قابلة للتكيف مع مثل هذه الأوضاع. المطلع على هذا الموضوع يلاحظ كماً كبيراً من الطروحات المقدمة لتحقيق هذا الهدف .

في هذه الرسالة يتم اعداد المجدول بحيث يستطيع أن يوزع موارد الشبكة على المستخدمين بشكل فعال و بضمان الخدمة النوعية التي يحتاجها كل مستخدم حيث سيعمل على تخصيص الموارد بناءً على حجم الطاقة المستهلكة لدى كل مستخدم بالإضافة لذلك سنستفيد من المجدول بخوارزمية الخط الذي يموت أولاً(Earliest Deadline First) والتي تمتاز بأداء ممتاز وأقل تأخير ممكن. عدة اشكال من هذا المجدول تم اقتراحها ومنها على سبيل المثال لا الحصر : المجدول بخوارزمية الخط الذي يموت اولا" ذا الطاقة الأدنى, المجدول بخوارزمية الخط الذي يموت اولا" ذا الطاقة الأعلى , المجدول بخوارزمية الخَطّ الميت أولاً و متعدد الحزم ذا الطاقة الادنى , المجدول بخوارزمية الخَطّ الميت أولاً و متعدد الحزم ذا الطاقة الأعلى. تم عمل تجارب محاكة عديدة بافتراض شبكة CDMA لها تسعة عشر خلية . التجارب أظهرت أداءاً متميزاً من خلال نتائج التدفق و تأخير استلام الحزم عند الاحمال المتوسطة و

المنخفضة بالإضافة لذلك اتضح أن احتمالات فقدان الحزم قليلة بالمقارنة مع المجدول بخوارزمية الخط الذي يموت اولا" الاصلي و المجدول بطريقة بخوارزمية الخَطّ الميت أولاً و متعدد الحزم. بالمقارنة مع هذين المجدولين فإن احتمالات الفقدان انخفضت بحوالي 25% و كذلك فإن التأخير في استلام الحزم انخفض بحوالي 70-80%. باستخدام مؤشر جوبن للاتصاف قارنا النتائج مع المجدول بخوارزمية الخط الذي يموت اولا" و المجدول بخوارزمية الخَطّ الميت أولاً و متعدد الحزم. و أخيراً أظهرت الدراسة مدى تأثير الفترة التي يتم النظر اليها في الجدولة على النتائج.

درجة الماجستير في الهندسة
جامعة الملك فهد للبترول و المعادن
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CHAPTER 1

INTRODUCTION

The rapid growth of wireless technology in the past few years, coupled with the explosive growth of the Internet is increasing the demand for wireless data services. Traffic on future wireless (3G& 4G) networks is expected to be a mix of real-time traffic such as multimedia teleconferencing, voice, and data-traffic such as WWW browsing and file transfers, with users desiring diverse Quality of Service (QoS) guarantees for different types of traffic [4]. Code Division Multiple Access (CDMA) will be the widely deployed air interface for next generation wireless networks [3][30].

We have two resources for wireless communications: power and the bandwidth and both of them are limited. Now to utilize these limited resources in an efficient way the concept of *Scheduling* plays an important role and it will help the network in providing the services with certain QoS. This chapter gives a brief introduction to CDMA, path loss model, and UMTS services. An introduction to Scheduling algorithms is provided with a classification on different schedulers.

.

1.1 Introduction to CDMA

CDMA stands for *Code Division Multiple Access*. It is an access method and air interface between the base station and mobile users. In CDMA, all users use the same channel (Frequency) simultaneously but use different spreading codes. All the codes have noise-like characteristics with very small cross-correlation [30]. A receiver can separate the information received from a particular user by using the spreading code allocated to this user. Although there is small cross-correlation between the code channels but as they are using the same channel at the same time, they may cause interference to each other. In addition, this interference limits the CDMA capacity.

1.1.1 Interference

Interference is the major limiting factor in the performance of cellular radio systems. Sources of interference include other mobiles in the same cell, a call in progress in a neighboring cell, other base stations operating in the same frequency band, or any noncellular system, which inadvertently leaks energy into the cellular frequency band. Interference on voice channels cause cross talk, where the subscriber hears interference in the background due to an undesired transmission. On control channels, interference leads to missed and blocked calls due to errors in digital signaling. Hence, Interference has been recognized as a major bottleneck in increasing capacity and is often responsible for blocked calls [27].

The two major types of system-generated cellular interference are co-channel interference and adjacent channel interference.

Co-Channel Interference

Frequency reuse implies that in a given coverage areas there are several cells that use the same set of frequencies. These cells are called co-channel cells, and the interference between signals from these cells is called co-channel interference. To reduce co-channel interference, separate the cells by a minimum distance. This provides sufficient isolation due to propagation [27].

Adjacent Channel Interference

Interference resulting from signals, which are adjacent in frequency to the desired signal, is called adjacent channel interference [27]. The cause of this interference is due to imperfect receiver filters, which allow nearby frequencies to leak into the pass band. Adjacent channel interference can be minimized through careful filtering and channel assignments. By keeping the frequency separation between each channel in a given cell, the adjacent channel interference may be reduced considerably.

1.1.2 Multimedia CDMA

A great deal of research is done on the following terrestrial multimedia CDMA systems, which are the basis for the IMT-2000 standard [7][30].

Wideband Frequency Division Duplex-FDD (Frequency Division Duplex) CDMA

Universal Mobile Telecommunications Service **(UMTS) Standard #1**: UMTS is developed by Qualcomm and adopted by Telecommunications Industry Association (TIA) in 1993. To accommodate larger multiple rates, an extended bandwidth per carrier is used (5MHz). The carrier frequency and bandwidth allocations are the following:

—Uplink 1920–1980 MHz (60 MHz total, 12 carriers)

— Downlink 2110–2170 MHz

—Supported bit rates range between 8 kbps–2 Mbps (information source rate).

Wideband Time Division Duplex-TDD (Time Division Duplex) CDMA-UMTS Standard -2

In this system the 5 MHz bandwidth is used for both the uplink and downlink directions during different time slots. The characteristics of UMTS-TDD are similar to those of GSM. Both FDD and TDD standards are used to make them suitable to coexist with GSM and allow the users to seamlessly hand over between all three systems.

Overlapped carrier-multicarrier CDMA: The spreading procedure is applied in the frequency domain. As in DS-CDMA (Direct Sequence-CDMA), a large number of orthogonal carriers transmit each user's signal (orthogonal frequency-division multiplexing). These carriers have partially overlapped spectral positions, which result in improved spectral efficiency.

1.1.3 UMTS Services

The multimedia services investigated for Universal Mobile Telecommunications Service (UMTS) by the European Telecommunications Standard Institute (ETSI) consist of the following four different classes [7]:

- ***Service class A*** (low-delay data) includes delay-constrained (20–50 ms) connection oriented services with BER (Bit Error Rate) $< 10^{-3}$ for the 8kb/s service and BER $< 10^{-6}$ for the higher bit-rate services (144–384 kb/s).

- ***Service class B*** (low-delay data) describes the delay-constrained (50 ms), connection-oriented, variable bit rate (VBR) services (peak rates 64/144/384/2048 kb/s) with Bit Error Rate BER $< 10^{-6}$.
- ***Service class C*** (long constrained delay) includes connectionless services with similar bit rates as in class B. Maximum delay is 300 ms and BER $< 10^{-6}$
- ***Service class D*** (unconstrained delay data) supports best effort connectionless services (peak rates 64/144/384/2048 kb/s). There are no delay limits, and BER $< 10^{-8}$.

The cellular configuration in UMTS supports various cell sizes, such as Pico cells (radius < 100m), micro cells (100 m < radius < 1km), and macro cells (radius > 1 km).

In this section, an introduction to CDMA was discussed and in the following section the hybrid scheme is introduced.

1.2 Hybrid TDMA/CDMA

TDMA/CDMA is a hybrid scheme, which has more advantages than individual CDMA or TDMA schemes. Most of the known wireless MAC protocols not specifically designed to support multimedia applications. Since a single protocol often cannot handle the *throughput and latency* demands of such applications, hybrid protocols are designed which combine the features of more than one protocols and thus perform better [5]. Multiple access schemes having at least CDMA or SSMA (spread spectrum multiple access) component are superior to other multiple access schemes because by these techniques, the frequency selectivity of the radio channel, that severely impairs the system performance, can be simplified.

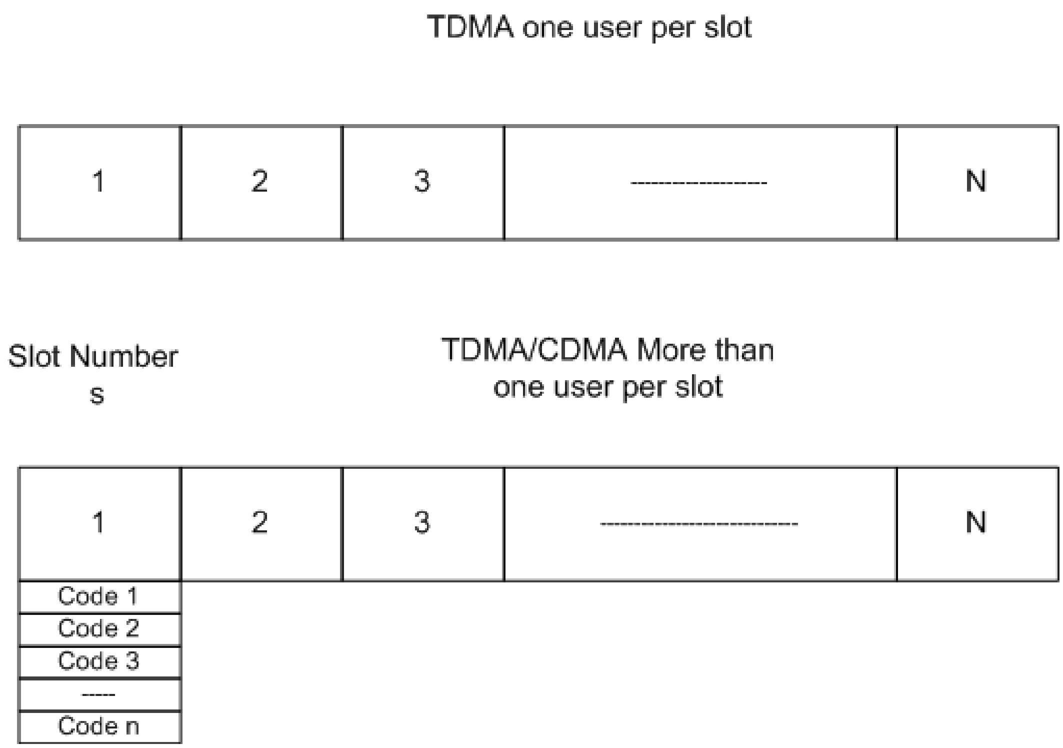

Figure 1.1: TDMA & TDMA\CDMA structure

Figure 1.1 above shows the difference between the TDMA and hybrid TDMA/CDMA. In TDMA, only one user can access one slot for transmission where as in hybrid TDMA/CDMA many users can access one slot with different orthogonal codes assigned to users to differentiate them. Basic notion behind the hybrid technique is to control interference in the CDMA system using TDMA type multiplexing. Packet traffic flows generated and transmitted to mobile users are time multiplexed on spread spectrum codes. Packet transmissions in code space control the interference among the users in each time slot in order to decrease bit error rate [2] [3][30].

Scheduling algorithms provide mechanisms for bandwidth allocation and multiplexing at the packet level. Admission control and congestion control policies are all dependent on the specific scheduling discipline used.

1.3 Quality of Service

QoS defined by International Telecommunication Union (ITU) as the collective effect of service performance that determines the degree of satisfaction of a user of the service. The end user decides whether he is satisfied with the provided QoS or not [7].

To provide multimedia services through wireless channels it is important that certain quality of service (QoS) parameters as specified by the application is satisfied. Conservative admission control schemes lead to satisfactory delivery of QoS but it will result in under utilization of channel resources. The aim is to strike a perfect balance between the number of users served and their degree of satisfaction. Schemes like efficient admission control, optimum resource management and good error control adopted to achieve this. Mobile terminals use connection-oriented services with dedicated data channels or connectionless services by competing for channels to satisfy their requirements [9]. Some of the QoS parameters are listed below.

1.3.1 QoS Parameters

In case of networking, (wired or wireless) widely used parameters are [6]:

1. Packet Delay
2. Throughput
3. Average power
4. Success Probability
5. Failure Probability

These parameters are used to estimate the QoS to cater to the needs of the end user. In order to cater to the needs of the user, different scheduling schemes applied to get optimum performance so that user gets satisfied with QoS.

1.4 Scheduling

Scheduling is the scheme of Time domain resource management. *Scheduling* is necessary to utilize limited resources in an efficient way. Some of the important resources in wireless communication are Power and Bandwidth [7]. Since these resources are limited, we need scheduling schemes to utilize these resources efficiently and to meet the wide-ranging QoS requirements of users

The scheduling algorithm determines the transmission order of packets in outgoing links and, thus it has a direct impact on the *packet delay* and *achievable throughput*, which serve as primary figures of merit of the system performance. Scheduling algorithms are essential for the support of delay-sensitive applications in integrated service networks.

The primary mission of the scheduler is to allocate *efficiently* the system *resources* to the users. In computer networks, the term “resources” refers primarily to the bandwidth of the transmission link, and the queuing buffer space in the routers, whereas the adverb “efficiently” refers to making sure that resources are not wasted (for example, in a TDMA system, the scheduler would try to ensure that as many as possible timeslots are used for transmission)[7].

1.5 Major Issues in Wireless Network Scheduling

The characteristics of wireless communication pose special problems that do not exist in wire line networks. These include: 1) high error rate and bursty errors; 2) location-dependent and time-varying wireless link capacity; 3) scarce bandwidth; 4) user mobility; and 5) power constraint of the mobile hosts. All of the above characteristics make developing efficient and effective scheduling algorithms for wireless networks very challenging [10]. Some of the wireless scheduling challenges are as listed below [10][30].

- Wireless Link Variability
- Fairness
- QoS
- Data Throughput and Channel Utilization
- Power Constraint and Simplicity

1.5.1 Wireless Link Variability:

Due to the high quality of the transmission media, packet transmissions on wire line networks enjoy very low error rate. Wireless channels are more error-prone and suffer from interference, fading and shadowing. The capacity of a wireless link has very high variability. Besides the time-dependent problem, wireless link capacity is also location-dependent. Mobility of the hosts increases the variability of the transmission links. Such link variations require the scheduling algorithms to be equipped with certain dynamic mechanisms that can deal with these time-dependent and location-dependent changes[30][10].

1.5.2 Fairness

A packet is scheduled for transmission on a wireless link according to certain service discipline or fairness guidelines transmitted independent of link state. If the link is in an *error* state and if the packet transmitted, it may be corrupted and the transmission will waste transmission resources. Deferring transmission of this packet until the link recovers from the *error* state is clearly a reasonable choice. The affected flow, hence, temporarily loses its share of the transmission bandwidth. To ensure fairness, the flow compensated for this loss later when the link recovers[30][10].

1.5.3 QoS

Wireless networks will provide services for heterogeneous classes of traffic with different QoS requirements. Therefore, QoS differentiation and QoS guarantees are supported. To achieve this goal, the corresponding mechanism for QoS support is integrated into the scheduling algorithm. For Differentiated Services type of services, prioritized scheduling service for aggregated traffic with QoS differentiation is implemented in the scheduling algorithm; whereas for Integrated Services type of services, support for per-flow-based guaranteed QoS performance, such as delay or jitter bound is provided by the scheduling algorithm [10].

1.5.4 Data Throughput and Channel Utilization

The most precious resource in wireless networks is the bandwidth. An efficient wireless scheduling algorithm should aim to minimize unproductive transmissions on error links, and at the same time, maximize the effective service delivered and the utilization of the wireless channels[10].

1.5.5 Power Constraint and Simplicity

A good scheduling algorithm is designed to minimize number of scheduling related control messages required from mobile hosts. A scheduling algorithm that needs to use every uplink packet's arrival time to compute scheduling order is not a good choice, because it demands a large amount of power from mobile hosts for transmitting the information of arrival times to the base station. In addition, the scheduling algorithm should not be too complex, so that it executes at high speed to schedule real-time multimedia traffic with stringent timing requirements[10].

1.6 Classification of Schedulers

Due to the various issues in wireless scheduling which discussed in the previous section there is a need for a good scheduling algorithm in the downlink as well as uplink to serve different classes of users. Scheduler can be classified in different ways depending on the main serving criteria. Some of the schedulers are summarized below [5][30].

Schedulers can be broadly classified into Work conserving and Non-work conserving

- *Work Conserving:* Scheduler is never idle if there is a packet waiting for transmission[5]. Examples of work conserving scheduler are General Processor Sharing (GPS), Weighted Fair Queuing (WFQ) etc.
- *Non-work-conserving:* Scheduler may be idle even if there is a backlogged packet in the system because it may be expecting another higher-priority

packet to arrive[5]. Examples are Hierarchical Round Robin (HRR), Stop-and-Go Queuing (SGQ), and Jitter-Earliest-Due-Date (Jitter-EDD).

Some of the schedulers can also be classified as:

- A *time stamped* scheduler is one that serves packets according to their timestamp values. The Head of Line (HOL) packets sorted in increasing order of their timestamps, and the packet with the lowest timestamp value selected for transmission. It can provide better QoS guarantees[5].
- *Sorted-priority* scheduler, each session has a different priority level and packets selected for transmission according to their session priority[5]. Examples are WFQ, and Jitter-EDD.
- *Frame-based* scheduler, time divided into frames of fixed or variable size. Each session reserves a portion of the frame for transmitting its packets[5].

On the other hand, another way of classifying schedulers is how to gather information to make scheduling decisions [5]:

  - Offline: knows about all requests and all channel capacities for all times
  - Online: knows about requests and capacity that have arrived up to time slot.

Offline algorithms are the optimal one and used to judge the online algorithms. In the following, few examples of online scheduling algorithms for CDMA are presented:

- *Processor sharing (PS):* General Processor sharing (GPS) [5] is an efficient, flexible, and fair scheduler originally proposed for use in an error-free environment. GPS possesses two desirable properties :

- It provides an end-to-end delay bound if the incoming traffic is well behaved (i.e., does not exceed its reserved rate).
- Processor sharing algorithms (for downlink) which attempt to "fair share" BS transmit power only finish up cooking the jobs uniformly .The QoS performance metrics suffer greatly. That is why in case of delay sensitive traffic it is very difficult to maintain QoS with PS algorithms.

- *Deadline based (EDF):* This scheduler assigns all the power to the user for which the deadline of the packet at the head of queue is closest [11]. Our proposed algorithms are the enhanced version of the deadline-based algorithms. In our proposed algorithms the packet is scheduled based on either minimum power or maximum power from all the arrivals whereas in EDF algorithm the packet is scheduled according to its deadline.

1.7 Thesis Layout

The thesis is organized as follows; Chapter 2 will address the current work on Qos oriented downlink scheduling algorithms. Chapter 3 will present the proposed work on downlink scheduling algorithms. Chapter 4 and Chapter 5 will present the comparison results of downlink scheduling algorithms. Finally, we conclude our work with major findings and future work in Chapter 6.

CHAPTER 2

LITERATURE REVIEW

The literature review gives an overview of different scheduling algorithms adopted in CDMA previously. Different scheduling algorithms adopted to cater the needs of users QoS. Research is still going on to improve QoS that is an important factor in scheduling. In this literature, different schedulers are classified according to work conservation, deadline based and power control. Lastly, emphasis is made on the research done in MAC protocol scheduling schemes, which uses CDMA/TDMA hybrid scheme.

Schedulers are classified in different ways depending on the main serving criteria. Some of the schedulers summarized below [5].

As in the previous chapter, scheduling algorithms are classified in accordance to the criteria of work conservation/non-work conservation, online scheduling algorithms. The classified scheduling schemes are discussed with their applications in the literature to get a good understanding of the classification. Below gives the scheduling classification studied in the literature with their applications on different scheduling schemes.

2.1 Literature Survey

A rate processor-sharing algorithm [8] is proposed for scheduling of Downlink traffic followed by further work in [11]. Matthew Andrews et al. [11]presented the CDMA downlink rate-scheduling problem for heterogeneous traffic with distinct QoS requirements. They proposed the Earliest Deadline First (EDF) algorithm that serves single packet in each slot.

Aikaterini C.Varsou et al. [12] studied the CDMA downlink rate scheduling problem for heterogeneous multiple packet traffic with distinct QoS requirements. The authors obtained better results than EDF algorithm. This algorithm serves the packet of the user at each time slot with earliest deadline. If the head packet is fully served and if there is still power left in the system they repeated the procedure with next earliest deadline user as long as the total traffic power is utilized.

Aikaterini C. Varsou and H. Vincent Poor [13] described the rate-scheduling problem for downlink of CDMA networks with heterogeneous topic with different QoS requirements. In this paper, authors compared HOLPRO with EDF and its modified version Powered Earliest Deadline First algorithm (PEDF). HOLPRO performed better than EDF & PEDF. In this algorithm at each time slot, a pseudo probability assigned to head of the packet of each user. The packet length normalizes the pseudo probability. The user with maximum normalized pseudo probability is served first and if there is power, remaining in the system the procedure is repeated with next maximum normalized quantity as long as power resources remain.

Zhuo Gao et al [14] studied the packet-scheduling scheme for downlink CDMA networks. They studied the packet-scheduling algorithm based on transmission time prediction. Packet serving time contains two parts: Queuing time and transmission time. A packet will be discarded if it exceeds deadline. Serving a packet to be discarded will waste limited power resources. To avoid this, PDSTTF algorithm is applied. This algorithm utilizes TDMA mode to transmit packets. M-PDSTTF algorithm is developed by authors to utilize the discrete transmission rate and constant scheduling interval. This scheduling scheme adopts a residual transmission power allocation mode. The results of M-PDSTTF show that it performs better than M-EDF and M-HOLPRO. M-HOLPRO performs better than M-EDF because M-HOLPRO assigns higher priority to smaller packet and decreases the average packet delay. M-PDSTTF performs better than M-HOLPRO because the former utilizes information of both packet size and user channel condition.

Aikaterini C. Varsou and H. Vincent Poor [15] proposed generalized versions of PEDF and HOLPRO as GPEDF and GHOLPRO, which performed better than the former algorithms. In the generalized version of PEDF (GPEDF), the packet with the minimum normalized deadline (deadline/packet length) is considered. This packet is the one that will characterize the user. Then the characteristic packets of each user compete with each other, and the one with the minimum normalized deadline will determine the user to be served. The serving criteria in GHOLPRO and GHOLPF are the same as in HOLPRO and HOLPF with the difference being that the characteristic packet of each user to be served is not necessarily in the head of the line but can be anywhere in the user's queue.

We notice from these results that as the number of users increases, it becomes harder to reach the QoS and hence the success probabilities decrease. GPEDF is slightly worse than PEDF as the number of users in the system increases, but this is due to the fact that the serving criteria function is slightly changed since in PEDF we have deadline and in GPEDF we have normalized deadline. A better sense of how the generalized and ungeneralized schemes compare can be obtained through the GHOLPRO and GHOLPF graphs, since the criteria functions between these and their corresponding HOLPRO and HOLPF versions are the same. The graphs reveal that the generalized schemes definitely perform better than their ungeneralized counterparts. Essentially, what happens is that there are substantially fewer bits going out of the system in the GHOLPRO, GHOLPF cases, but all of these packets satisfy their QoS guarantees. In HOLPRO, HOLPF, more packet**s** pass through but fewer of them have their requirements met.

Ashraf S.H.Mahmoud, M.A.Razzaque [16] proposed algorithms, DEDF and DPEDF which are compared against the original continuous bit rate EDF and PEDF in terms of network throughput, power utilization, and packet discard rate for typical 3G network deployment parameters. Results indicate the use of discrete service rate reduces maximum network throughput and lowers the power utilization. Finally, the study also evaluates the effect of various packet delay thresholds on the overall performance of the network.

Lei Zan et al. [17] studied packet delivery to mobile stations in a fair manner and at the same time takes into consideration the channel conditions for power efficiency. In this paper, the authors presented a Fair channel dependent scheduling algorithm for real time traffic on CDMA downlink. This algorithm achieves timely delivery of packets to minimize the packet drop rate. It also achieves fairness to each mobile station. This algorithm performs better than FCFS by considering less power and it displays lower packet drop rate and exhibits more fairness than BCF (Best channel first algorithm).

Juang –Ho Yoon et al. [18] studied optimal scheduling methods to increase the packet service efficiently. They classified the scheduling schemes providing bounded delay into three categories: Static Priority (SP), EDF and rotating priority queuing (RPQ). In SP queues are provided for each traffic class and packets are serviced according to the priority of the queues. EDF uses only one queue. RPQ has queues for every traffic and provides services to packets according to the priority of the queues. RPQ is dynamic where as SP is static where the queue priority cannot be changed during the process. These schemes are applied to interference limited CDMA system and the results are compared by considering both data loss rate and transmit power level. The modified FIFO scheme outperformed the original FIFO scheme. The performance of all the above scheduling methods is improved by using modified FIFO algorithm. The performance of EDF was good but its complexity is high .SP and RPQ with modified FIFO scheme that gives better results than EDF with basic FIFO in terms of lower data loss rate. This infers that modified FIFO is employed to SP and RPQ, thus performing scheduling with low complexity, efficient transmission and low transmission loss rate.

RPQ has a queue for each traffic class and provide services according to priority of queue; it can reduce the complexity, which is unavoidable in EDF. In EDF, It calculates the deadlines of all packets. After sorting the packets by increasing deadline user, it services sorted packets. Its performance is better than SP and RPQ but it needs calculations and sorting every time a new packet enters a queue and this leads to RPQ algorithm.

Daisuke Kitazawa et al. [19] focus on packet scheduling aimed at utilizing radio resources efficiently while supporting users QoS. The authors focus on achieving efficient power resource utilization and supporting users QoS by employing packet scheduling to utilize base station transmission power efficiently and to monitor buffering delay of packets. Two schemes have been introduced i.e., STPD (Scheduling with transmission power and packet delay) and STPD-SPF (Smallest powered packet first) are proposed and the performance for voice and data traffic is evaluated. The proposed schemes exhibit better performance than FIFO in packet loss of voice traffic and average transmission rate of data traffic.

The main difference between the SPF (Shortest Power Packet First) and MinPower EDF is that in the former case, buffering delay is not taken into account but in the later case delay threshold, the important QoS parameter is considered thus affecting the performance measures. In SPF algorithm, the packets are divided into two groups the packets with less power (Group 1) and packets with higher power (Group 2). The Group2 packets are rarely get transmitted as highest priority is given to the Smallest Power Packet first. In MinPower EDF algorithm, the Min Power packet from the current time slot is given the highest priority. These packets are contended again into the next slot with the arrivals happening in that slot.

Isaias Lopez et al. [20] studied diverse packet scheduler algorithms and determined their impact on packet delay, throughput and packet call delay. They proposed the modified round robin algorithm that provides a fair sharing of resources with higher network throughput than plain round robin. Results showed that the modified round robin algorithm is a trade off between carrier to interference ratio (C/I) based and round robin scheduling.

In [21]the authors present an analytical study for an optimal discrete one-rate scheduler for power-efficient transmission over wireless links. The study takes into account delay constraints and provides performance bounds for networks supporting multi-rate schedulers.

Table 2.1 summarizes the different existing scheduling algorithms in the literature with access scheme used, parameters used, traffic sources used and type of study used.

Table 2.1: Comparison of different Scheduling algorithms [30]

Algorithm	Access Scheme	Parameters Used	Traffic Sources Used	Study	References
EDF	CDMA	Packet Delay Bound	On-Off (Bursty) Poisson (CBR)	Simulation	[11]
PEDF	CDMA	Packet Delay Bound and Residual power classification	On-Off (Bursty) Poisson (CBR)	Simulation	[12]
HOLPRO	CDMA	Packet Delay Bound, packet size and power classification	On-Off (Bursty) Poisson (CBR)	Simulation	[13]
M-PDSTTF	CDMA	Packet Delay	On-Off	Simulation	[14]
G-PEDF and G-HOLPRO	CDMA	Packet Delay, Packet Size	On-Off	Simulation	[15]
EPG	CDMA/ PRMA	Power grouping, packet delay	Voice, video and data traffic	Simulation	[25]
STPD & STPD-SPF	CDMA	Packet loss rate, Avg. Transmission rate, QoS satisfaction rate	Voice and Data traffic	Simulation	[19]
Power Control-II	TD-CDMA	Delay bound, Packet loss ratio, BER, Max.Packets per slot	Voice, Video (CBR, VBR),Data (ABR),Email	Simulation	[22]
GPS	TDMA/ CDMA	Using weights	ON/OFF model	Simulation	[23]
CDGPS	TDMA/ CDMA	Max.Delay, Throughput	Voice, Video and Best effort data	Simulation	[23]
WISPER	TDMA/ CDMA	Classification using BER	Voice, video, audio, email (ABR)	Simulation	[24]
FPLS	TDMA/ CDMA	Packet loss sharing using priority	On-Off (Bursty) Video and Data	Simulation	[2]

CHAPTER 3

PROPOSED WORK

3.1 Motivation

The motivation behind this proposal is that in the literature we could find several schemes like EDF, PEDF and SPF that cater the QoS needs of heterogeneous traffic. The main difference between the SPF (Shortest Power Packet First) and MinPower EDF is that in the former case, buffering delay is not taken into account but in the later case delay threshold, the important QoS parameter is considered thus affecting the performance measures. In SPF algorithm, the packets are divided into two groups the packets with less power (Group 1) and packets with higher power (Group 2). The Group2 packets are rarely get transmitted as highest priority is given to the Smallest Power Packet first. In MinPower EDF algorithm, the Min Power packet from the current time slot is given the highest priority. These packets are contended again into the next slot with the arrivals happening in that slot.

Therefore, in this Thesis, we will aim at providing the QoS by studying the effect of scheduling interval and delay threshold. This scheduler shall assign "channels" to contending users based on a set of criteria, namely, 1) the mobile stations’ estimated transmitter power, 2) user-preset transmission rate and 3) QoS constraint. The QoS constraint could be composed of one or a set of parameters. For example, a user may look for satisfying delay requirement, minimum throughput requirement while guaranteeing minimum transmission rate assignment.

The scheduler works as follows. Every channel assignment is put in a pool where all waiting requests are ordered in increasing order of their power requirements. Then packet delay of the request is checked. If the packet delay is within the delay threshold then this user is given higher priority over others and the channel is assigned to that User. The scheduler assigns a channel with corresponding transmission rate that is a function of offered load, packet size and scheduling interval size.

3.2 Problem statement

Requests arrive to the basestation according to a Poisson process with rate λ requests per second. Each request comes from a different mobile with a random location .The request is of random size. Algorithms for downlink scheduling have some shortcomings such as:

1) Earliest Deadline algorithm employs earliest deadline packet scheduling which may not be efficient for heterogeneous traffic to achieve maximum aggregate throughput.

2) These algorithms suffer from Head of Queue problem where packets at head of the queue may block other packets from service because of power shortage to serve the packet at the head of the queue.

In the literature, several burst admission and scheduling schemes have been discussed. In this Thesis, we modify and enhance the algorithms EDF and PEDF, which use continuous bit rate. The proposed algorithms that also use continuous bit rate are MinPower EDF, MinPower PEDF, MaxPower EDF and MaxPower PEDF based on Qos parameter delay threshold. The proposed algorithms will be compared with the original continuous rate EDF and PEDF algorithms in terms of throughput, power utilization and packet success rate and packet delays. The effects of scheduling interval and delay threshold are extensively studied. The motive of this study is to achieve the objectives listed below:

3.3 Objectives

- To propose and evaluate scheduling algorithm providing QoS over TDMA/CDMA.
- To compare EDF scheduler with MinPower EDF Scheduler and MaxPower EDF Scheduler and Compare PEDF scheduler with MinPower PEDF Scheduler and MaxPower PEDF Scheduler by using continuous bit rate.
- The comparison and evaluation will be conducted based on the many criteria such as: average power, throughput, success rate, discard rate and packet delays.

3.4 System model

The system model used is a typical deployment scenario of mobile CDMA network for downlink scheduling. This model will help to compare the continuous bit rate EDF and PEDF scheduling algorithms in terms of QoS parameter like delay threshold. We studied the performance through the simulation.

3.5 Proposed Algorithms

As discussed in the literature, EDF [11] and PEDF [12] algorithms, serve the packets based on their arrival times. Many authors studied the parameters that satisfy the QoS requirements. However, the present work proposed few modified forms of EDF and PEDF algorithms, based on the power of user's packets in the following sections. Moreover, extensive simulation runs have been conducted to study the effects of different parameters such as Scheduling Interval, Delay Threshold, and Tolerable Delay etc on throughput, average power, Success transmission and Packet discarded. The power-based algorithms are classified into Min Power EDF, MaxPower EDF, MinPower PEDF and MaxPower PEDF. The details of these algorithms are discussed in this chapter.

The proposed algorithms focus on the queue structure as the EDF algorithm suffers from Head of queue problem. However, EDF and PEDF algorithm employs FCFS scheduling which may not be efficient for heterogeneous traffic where delay is very important factor. The packets at the head of queue may block other packets from service because of power shortage to serve the packet at the head of the queue.

QoS defined by ITU as the collective effect of service performance that determines the degree of satisfaction of a user of the service. The end user decides whether he is satisfied with the provided QoS or not.

The Qos parameters considered here is delay threshold. This delay threshold is defined as the threshold beyond which the packet is discarded. It is the maximum delay for the packet to get scheduled in the slots successfully. This is user-defined parameter.

In MinPower and MaxPower, Qos parameter i.e. delay threshold is taken into consideration so that the other packets will not starve .If the packet reaches the delay threshold it gets discarded giving chance to other packets in the queue at the base station.

3.5.1 EDF algorithm

In the Earliest Deadline First algorithm (EDF), the main rate-scheduling scheme assigns all power to the user for which the deadline of the packet at the head of queue was closest. Only one user is served in each slot. This algorithm is the online scheduling algorithm and the arrivals arrive dynamically.

3.5.2 MinPower EDF algorithm

The modified form of EDF algorithm called Minimum Power EDF serves the packet of the user, which needs minimum power irrespective of its arrival times This algorithm searches the power requirements of the packet among all packets received before the current time slot and not yet served by giving priority to minimum power packet.

Assume the total traffic power of the slot is P. If power to transmit (P') is greater than the traffic power then the packet is served partially and the remaining part is served as a new packet in the next slot. If power to transmit the packet is less than the traffic power then serve the packet completely. This algorithm also satisfies the QoS requirements by checking the delay of the packet .If the delay of packet is greater than the delay threshold it is discarded. Single packet is served in each time slot.

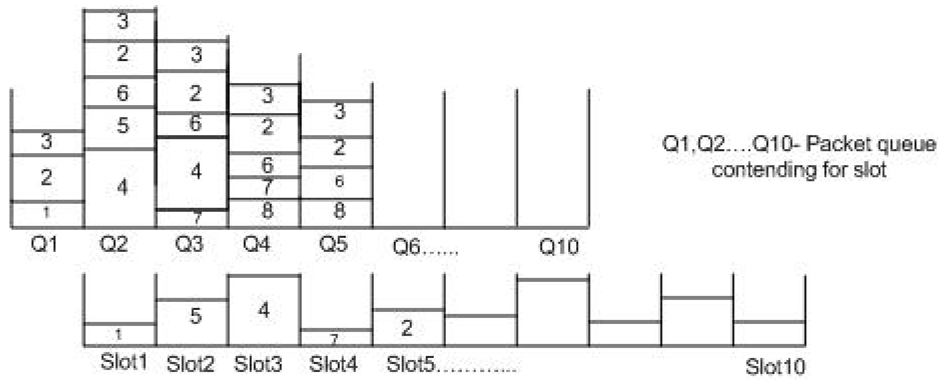

Figure 3.1: Figure showing the packets scheduled in slots for MinPower EDF algorithm

The Figure 3.1 above shows the operation of the algorithm pictorially. This algorithm runs at the base station. The algorithm selects the minimum power packet to be transmitted from the queue and allocates that packet in the slot. As shown in Figure 3.1 packet1 has minimum power among the arrivals. The remaining packets from the Q1 along with the packets arriving before the second slot are contending for slot2. From the Figure 3.1 it is clear that packet 5 is having the minimum power so it will be served in slot2. The process continues as such till the end of the simulation.

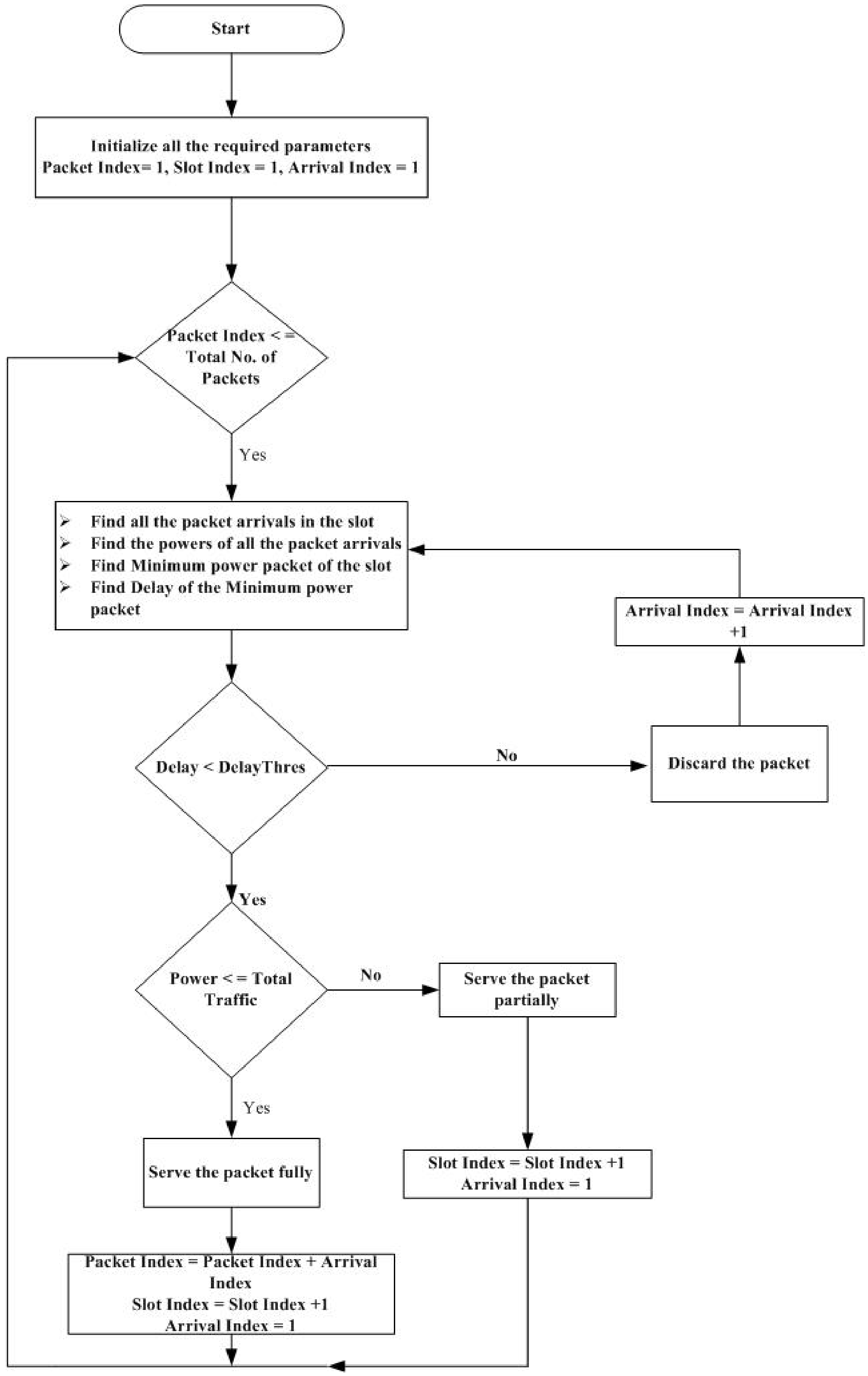

Figure 3.2: Flowchart showing MinPower EDF Algorithm

Algorithm 3- 1: MinPower EDF Algorithm

1. *Position users in cell. Compute their locations.*
2. *Generate traffic for every user.*
3. *For every time slot in the slotted window*
    a. *Find the user with minimum power from all the arrivals in that time slot and the packets arrived in the previous slots.*
    b. *If the power is not enough to serve the packet completely (P'>P) serve as much as you can in that time slot and serve the rest as a new packet in the next time slot.*
    c. *Otherwise (P'<=P)*
        i. *Decide to serve the packet completely*
        ii. *Find the power left in the system*

3.5.3 MinPower PEDF Algorithm

In this algorithm multiple packets of minimum power are served in each given time slot. The packet selection depends on the deadline of the minimum power packet. The minimum power packets are chosen and served in that slot until the power of the slot gets exhausted as the packets being served in the Powered Earliest Deadline First algorithm (PEDF) i.e. if we reach a point where not enough power is left, serve part of the packet and go to the next slot. This approach decides to serve more than one packet if there is enough power in the slot.

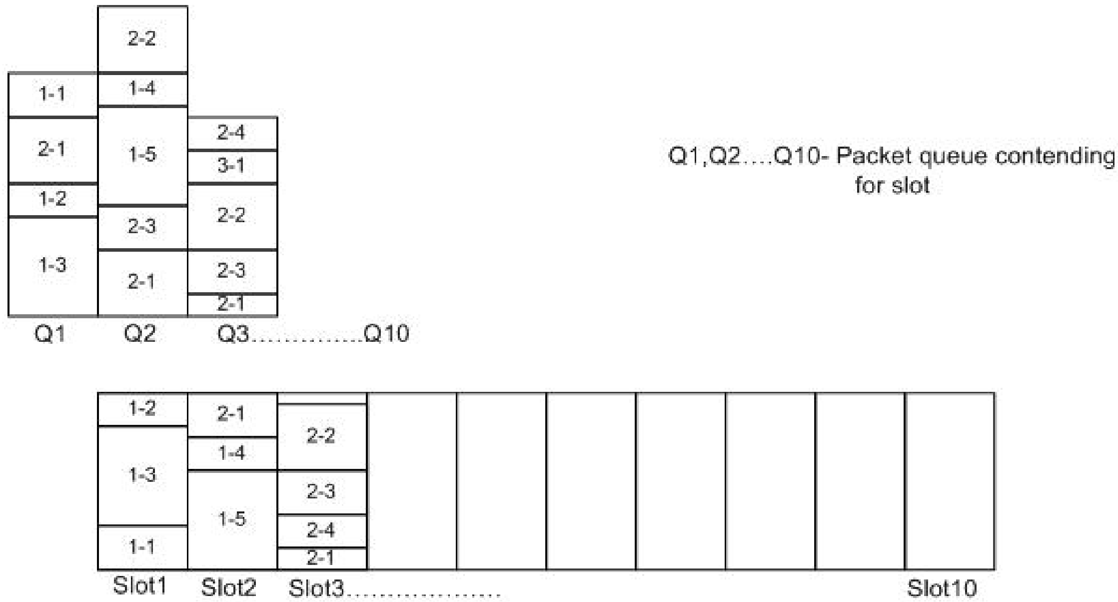

Figure 3.3: Figure showing the packets scheduled in slots for MinPower PEDF algorithm

The Figure 3.3 above shows the operation of algorithm pictorially. This algorithm runs at the base station. For example, arrivals at the same time will be queued together in one queue and so on for the other instants. We should note that this is just an example for illustration. In practice, we have one queue for each class of users. The algorithm selects the minimum power packet to be transmitted from the queue and allocates those packets in the slots.

As shown in Figure 3.3 the packets in the Q1 are of user1 (packet1, packet2 and packet3) and user2 with only one packet (packet1). The algorithm selects the minimum power packets from all the arrivals. After running the algorithm the minimum power packet is of user1 with packet1 of all the arrivals. This is scheduled in the slot1. Then again the algorithm is run till all the power of the slot is utilized. The next minimum power packet is packet3 of user1 and then packet2 of user1 are scheduled in slot1. Again the algorithm is run to see if the slot1 can accommodate more packets. When the algorithm is run again it is observed that the power of the slot is fully utilized and thus the remaining packets are contended to the next slot along with the arrivals happening in that slot. In case if the power still remains a part of the packet is scheduled and the remaining is scheduled in the next slot. This repeats till the end of the time frame.

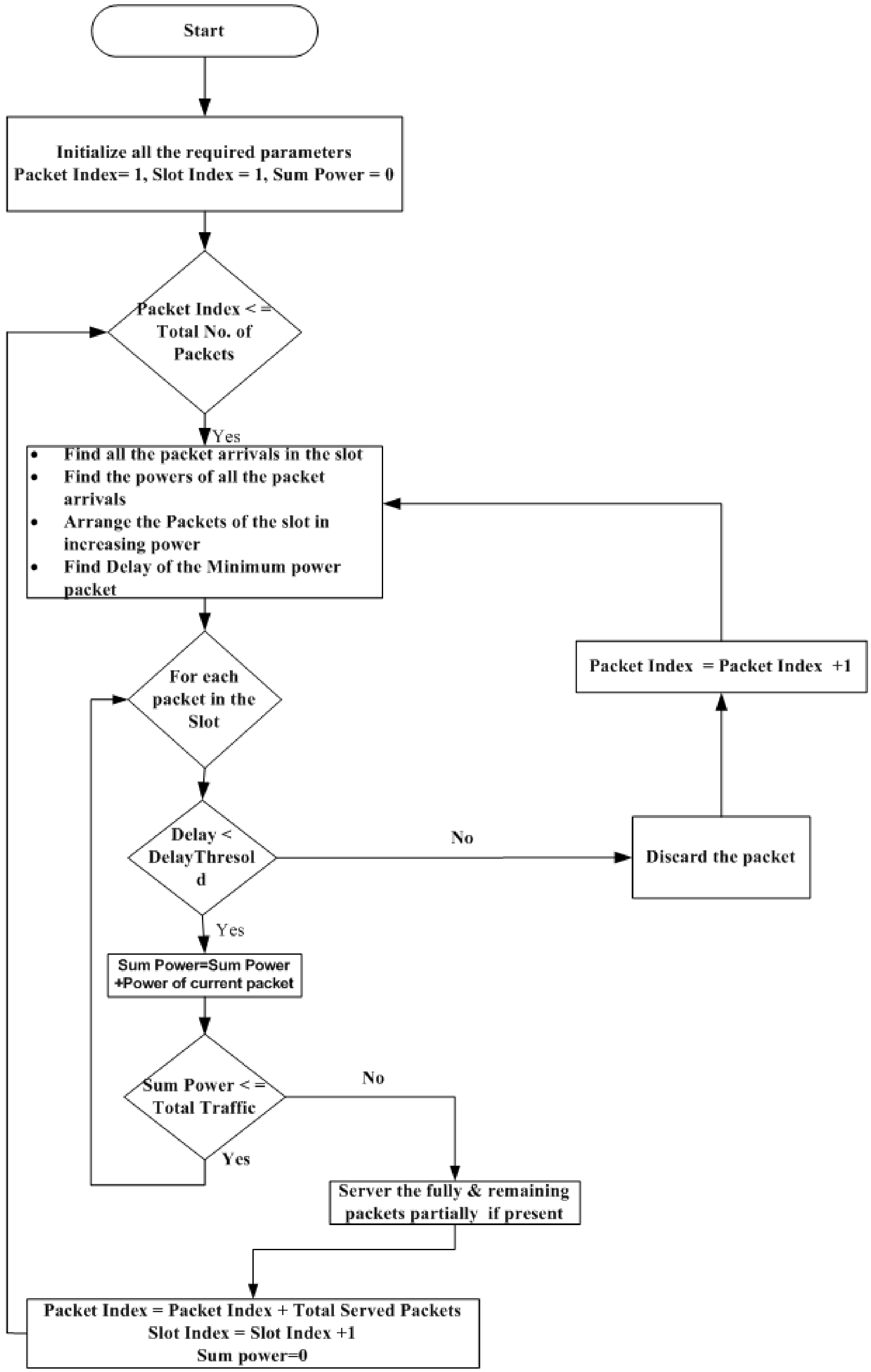

Figure 3.4: Flowchart showing MinPower PEDF algorithm

Algorithm 3- 2: MinPower PEDF Algorithm:

1) Position users in cell. Compute their locations.
2) Generate traffic for every user.
3) For every time slot in the slotted window
    a. Compute the power (P') required to transmit the packet. Find the user with minimum power from all arrivals before that time slot.
    b. Compute the marginal power (P") required by all previous packets that were to be transmitted during this slot, to account for the interference due to this new packet.
    c. If the power you gave him is not enough to serve his packet completely (P'>P-P"), decide to serve as much as you can in this time slot and go to the next slot.
    d. Otherwise
        1. Decide to serve the packet completely
        2. Find the power left in the system.
        3. Go to (a)

3.5.4 MaxPower EDF algorithm

The modified form of EDF algorithm called Maximum Power EDF serves the packet of the user, which requires maximum power irrespective of its arrival times This algorithm searches the power requirements of the packet among all packets received before the current time slot by giving priority to maximum power packet.

The total traffic power of the slot is P. If power to transmit (P') is greater than the traffic power then the packet is served partially and the remaining part is served as a new packet in the next slot. If power to transmit the packet is less than the traffic power then serve the packet completely. This algorithm also satisfies the QoS requirements by checking the delay of the packet .If the delay of packet is greater than the delay threshold it is discarded. Single packet is served in each time slot

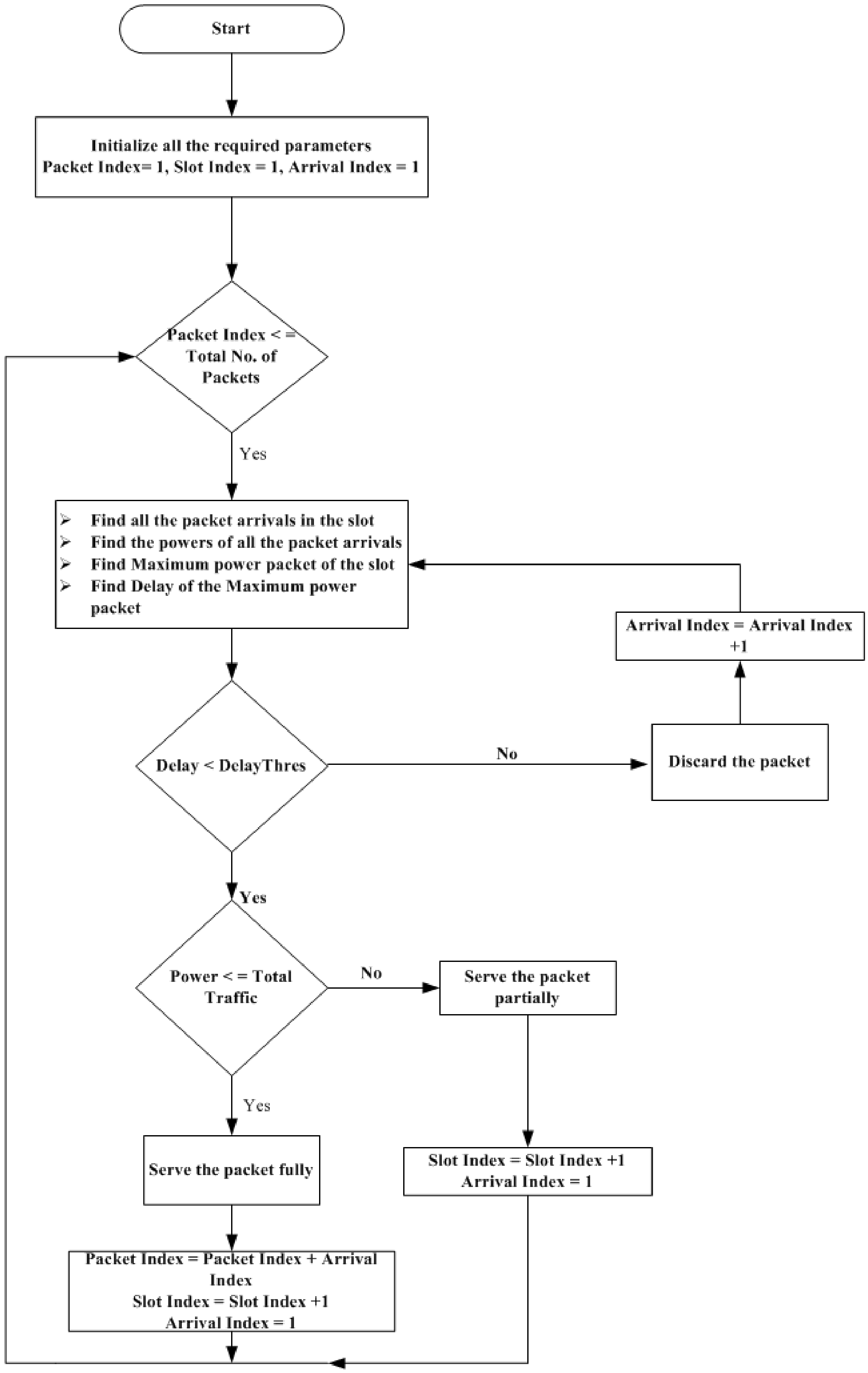

Figure 3.5: Flowchart showing MaxPower EDF algorithm

Algorithm 3- 3: MaxPower EDF Algorithm

1. *Position users in cell. Compute their locations.*
2. *Generate traffic for every user.*
3. *For every time slot in the slotted window*
    a. *Find the user with maximum power from all the arrivals in that time slot and* also the packets arrived in the previous slots..
    b. *If the power is not enough to serve the packet completely (P'>P) serve as much as you can in that time slot and serve the rest as a new packet in the next time slot.*
    c. *Otherwise (P'<=P)*
        i. *Decide to serve the packet completely*
        ii. *Find the power left in the system*

3.5.5 MaxPower PEDF algorithm

The proposed algorithm is a modified version of the PEDF algorithm. This algorithm gives priority to maximum power packet first in the decreasing order. This algorithm will fully utilize the traffic power of the slot. Considering the arrivals happen in the previous slot, the maximum power packet is selected to serve in that slot. If the power remains then the next highest power packet selected until the total traffic power utilized. If some full packets served and still there is power remaining then part of the packet is served and the remaining part is considered as new packet in the next slot along with the new arrivals. The algorithm illustrated below.

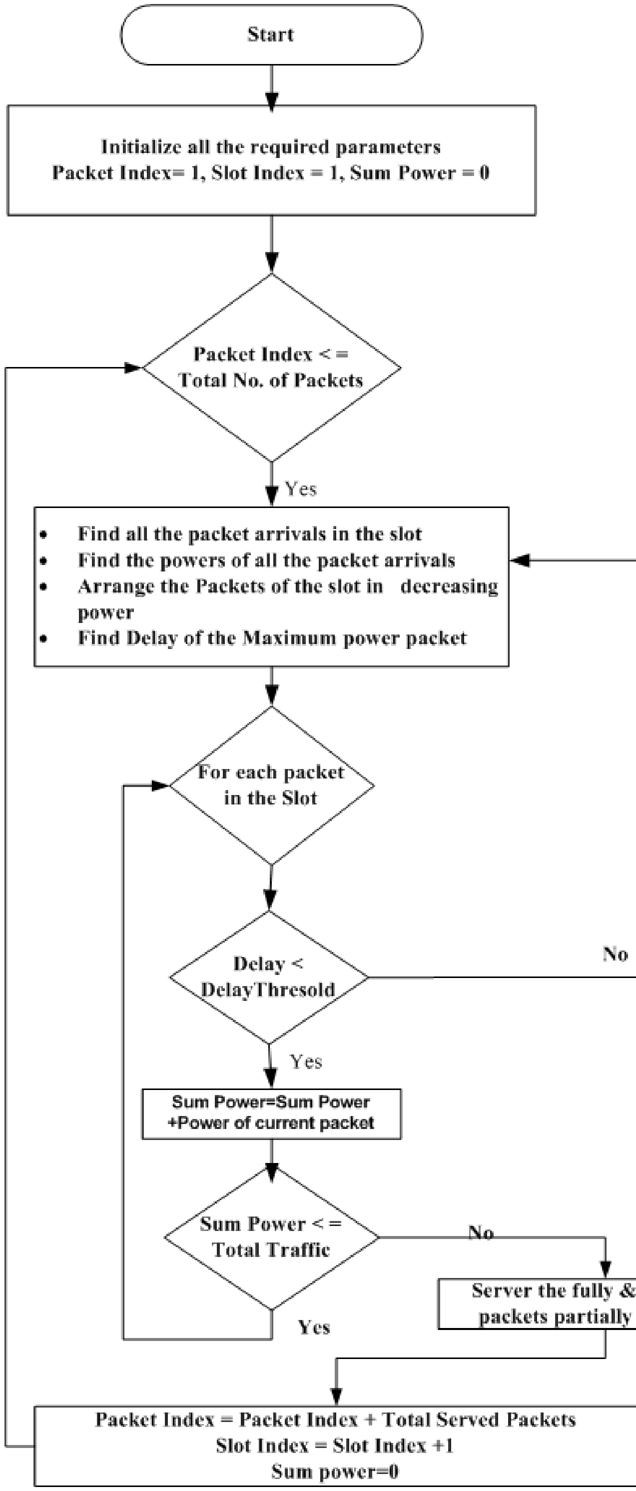

Figure 3.6: Flowchart showing MaxPower PEDF algorithm

Algorithm 3- 4: MaxPower PEDF Algorithm

1) Position users in cell. Compute their locations.
2) Generate traffic for every user.
3) For every time slot in the slotted window
    a. Compute the power (P') required to transmit the packet. Find the user with maximum power from all arrivals before the time slot.
    b. Compute the marginal power (P") required by all previous packets that were to be transmitted during this slot, to account for the interference due to this new packet.
    c. If the power you gave him is not enough to serve his packet completely (P'>P-P"), decide to serve as much as you can in this time slot and go to the next slot.
    d. Otherwise
        1. Decide to serve the packet completely.
        2. Find the power left in the system.
        3. Go to (a)

3.6 Performance Metrics:

The following are the performance metrics used to evaluate the effects of scheduling interval and delay threshold on the proposed algorithm. Some of them are listed below.

1. Packet Delay: This parameter is defined as the delay the packet undergoes in the base station before it is transmitted. A QoS Delay threshold parameter is the

threshold beyond which the packet gets discarded or gets corrupted. The Packet Delay is calculated using the formula

D_i = Current Time-Arrival Time.

$$\overline{D} = \frac{(\sum D_i)}{N}$$; N is number of successfully transmitted packets.

2. Throughput: It is the average bit rate, which is calculated using the formula

   R_i=packet size/Slot duration.

   Aggregate Throughput= $\sum_{i=1}^{N} R_i = \frac{1}{k}\sum \frac{B(i)}{SI}$;

   k is number of slots throughout the simulation time,

   $B(i)$ is the packet size,

   SI is scheduling interval

3. Average power: It is the power used to transmit the packets over the downlink, which is calculated using the formula.

   $$P_{av} = \frac{\sum_{i=1}^{k} P_{si} * SI}{T_{sim}}$$; k is number of slots, T_{sim}= Simulation time

4. Success Probability: The probability of transmitting the successfully transmission packets is defined as success probability.

   Success Probability=Total number of successfully transmitted packets / Total no of generated packets.

5. Failure Probability: It is the probability of discarding the packets, which are the complement of success probability.

   Failure probability =1-Success probability.

6. Fairness Index [31]: The fairness index is calculated using the formula

$$f(Thr_1, Thr_2 ....Thr_J) = \frac{\left(\sum_{i=1}^{J} Thr_i\right)^2}{J\sum_{i=1}^{J} Thr_i^{\,2}}, \; Thr_i = \sum_{j=1}^{N_j} R_i \text{ , } j\text{th user,}$$

Where $Thr_i = Thr_1, Thr_2, \ldots, Thr_J$ -set of user throughputs and J – no of users.

3.7 Simulation Parameters:

Here are listed some input system parameters that are used to study our proposed algorithms. Other parameters will be presented in chapter4.

1. Scheduling Interval: It is defined as the interval during which the packets are scheduled in the slots at base station. This scheduling interval varies from 5ms - 20ms to see the effect on throughput, power, success rate.
2. Delay Threshold: This is defined as the threshold beyond which the packet is discarded. It is the maximum delay for the packet to get scheduled in the slots successfully. This is user-defined parameter.

CHAPTER 4

SIMULATION MODEL

4.1 Simulation Model [16]

This section gives an overview of the simulation model used in this work. This chapter describes the model used for the traffic and the network model used in the simulation. This simulation model is taken from the paper [16]. The two state on-off Markov model [27] is used in traffic modeling. In the network model, two tiers of interferers are used to simulate the bursty data traffic in a wireless environment. Hata path loss model [26] is used to calculate the path loss. The traffic model and network model used in simulating the bursty data traffic are explained below.

4.1.1 Traffic Modeling [16]

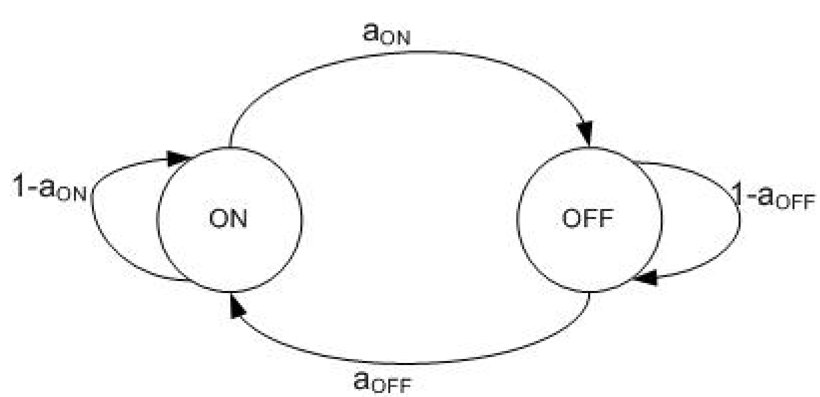

Figure 4.1: Two state markov model

Figure 4.1 shows the two states Markov model [27], which alternates between ON and OFF states. The traffic duration is divided into 'on' and 'off' periods. During the 'on' period, the duration of the packets arrive according to Poisson Process whereas during off period no arrivals occur. The 'on-off' durations are exponentially distributed with means of 0.2 seconds and 1.0 second respectively. The packet size is also exponentially distributed. The arrival rate of packets during the on period is equal to 20 packets per second and the Mean packet size is 10000 bits.

4.1.2 Network Modeling [16]

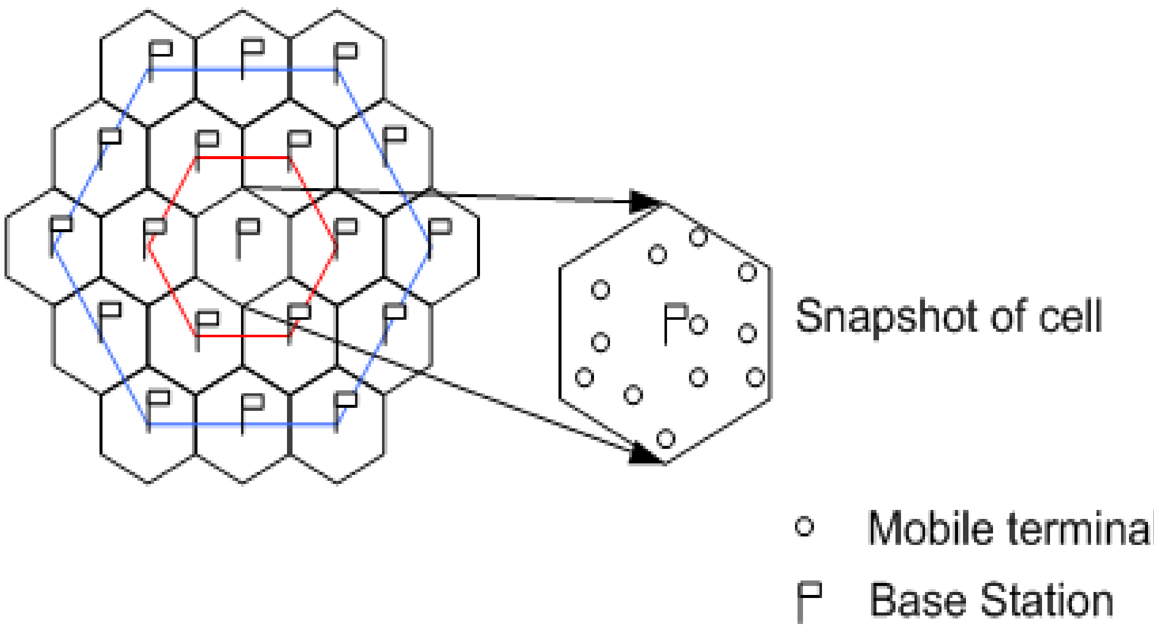

Figure 4.2: Cellular structure with 2 tiers of co-channel interferers

Each cell has one base station centered in the middle of the cell with N users uniformly distributed over the cell. The wired network interconnects the base stations. Each Base Station (BS) communicates with the mobiles using CDMA access scheme or air interface. The traffic goes from the BS to mobile, packets are scheduled according to the

MinPower or MaxPower algorithm in the BS and the packets are delivered to the destination mobile. In the downlink transmission the BS knows the required transmission power of each packet and the packet scheduler is deployed in the BS. The transmission from BS to mobile is wireless. As there is no wired network the path losses has to be considered. This path loss is calculated using the standard Hata path loss model formula. The time frame is divided into slots. The packets are selected according to the algorithm applied in the base station by scheduling the packet in the required slot. In multiple packets scheduling the interference between the packets is also considered. After the packets are scheduled in the slots, the packets are sent to the destination mobile from the base station to mobile.

The operation of the algorithm runs within the cell since handoff is not considered. This algorithm takes requests of the candidates within the cell of interest by considering the intraferance within the cell and the interference of the two tiers of interferers that are considered in the simulation.

The simulation utilizes the Hata radio frequency propagation model to calculate the path loss gains associated with every pair of transmit-receive locations. L_{ij} denotes the path loss between ith user and the jth cell. The path loss formula used in this model is Hata path loss model [26]. The Hata model is an empirical formulae. The standard formula for median path loss is given by [27].

$$Lij = 69.22 + 26.16 \log f_c - 13.82 \log h_b - a(h_m) + [44.9 - 6.55 \log h_b] \log d \qquad (4.\ 1)$$

Where f_c is the frequency (in MHz),

h_b is base station antenna height in meters,

h_m is mobile antenna height in meters,

d is distance in kms.

$a(h_m)$ is correction factor for mobile antenna height, which is a function of the size of coverage area.

The path losses are considered between the user to the base station within the cell and also the path loss between base station of different cells and the user within the cell of interest. These path losses are calculated accordingly for their respective interferences. They are the inter cell interference and intra cell interference.

Intra_cell_interference is the interference within the cell. This interference is the interference from other users, which affect the transmissions of the user of interest. This interference is calculated using the formula. A value of ρ (orthogonal loss factor) is considered while calculating the intra_cell_interference since the forward link transmissions are not perfectly orthogonal. If ρ is zero then it is said to be perfectly orthogonal.

Inter_cell_Interference is the interference between the cell of interest and the other surrounding cells. In the simulation a total of 19 cells are considered. The center cell is the cell of interest and other 18 cells are the interferers. Thermal noise is neglected in all the calculations. This is because thermal noise power is negligible when compared to the interference power.

In the simulation a total power P_t is allocated for data transmission from base station to mobile. For overhead channels certain fraction of power, $\beta * P_t$, is allocated for signaling, pilot channels and sync purpose. Then, the total traffic power allocated for transmission is $(1-\beta) P_t$.

The cell of interest is transmitting with power P_t and the co-channel interferers are also transmitting with the same power.

$$\left(\frac{E_b}{N_0}\right)_i = \frac{W}{R_i}\frac{L_{i0} \times P_i}{\rho L_{i0}\left(\sum_{j=1,j\neq i}^{m} P_j + \beta P_t\right) + \left(\sum_{j=1}^{m} P_j + \beta P_t\right)\sum_{k=1}^{18} L_{ik}} \tag{4. 2}$$

Where $\left(\frac{E_b}{N_o}\right)_i$ is required bit energy to noise ratio

W is bandwidth in MHz

R_i is rate in Kbps

P_i is power of the packet

L_{ij} is path loss in dBs.

The first summation term in the denominator represents the intra cell interference. This interference comprises of the product of summation of powers of all users with in the cell and path loss between the ith user and the cell of interest. The second summation term in the denominator represents the inter cell interference. This interference comprises of the product of summation of powers of users in the cell of interest and the summation of path losses between ith user and the 18 interferers. The numerator represents the signal, which is the product of the power of the packet and the path loss between ith user and the cell of interest. This part of the equation gives the signal to interference ratio. The required bit energy to noise ratio is calculated by multiplying the signal to interference ratio with *W/R*. This gives the signal to noise ratio at the receiver.

Dividing numerator and denominator with L_{i0} results in this equation.

$$\left(\frac{E_b}{N_0}\right)_i = \frac{W}{R_i}\frac{P_i}{\rho\left(\sum_{j=1,j\neq i}^{m} P_j + \beta P\right) + \left(\sum_{j=1,j\neq i}^{m} P_j + \beta P\right) f_i} \tag{4. 3}$$

where $f_i = \dfrac{\left(\sum_{k=1}^{6} PL_{k0}\right)}{PL_{i0}}$

f_i represents the ratio of sum of path loss coefficients between the *i*th user and all the interfering cells to the path loss coefficient between the *i*th user and the cell of interest. This f_i is the function of mobile location in the cell of interest. This value is calculated offhand and approximated using polynomial of 7th degree. Table 4.1 summarizes the simulation parameters used in the simulation

Table 4.1: Simulation parameters [16]

Parameter	**Value**
Bandwidth (W in MHz)	1.25
Overhead factor (β)	0.2
Orthogonal loss factor (ρ)	0.1
Transmission Power (P_t) in watts	24
$\left(\frac{E_b}{N_0}\right)_{Threshold}$	5dB
Scheduling interval	5ms-20ms
Delay Threshold	100ms-500ms

CHAPTER 5

RESULTS AND DISCUSSION OF MIN POWER EDF AND PEDF ALGORITHMS

This chapter presents the performance of the proposed algorithms and discusses comparatively with the EDF and PEDF algorithms. The results are obtained for various QoS parameters such as Scheduling Interval and Delay Threshold. The delay threshold ranges from 100ms - 500ms and Scheduling Interval ranges from 5ms - 20ms. These ranges for delay threshold are selected to see the effect of success rate and the failure rate due to the delay threshold constraint. It can be seen that the stricter delay thresholds lead to situations where more offered load is required to allow the network to reach the maximum throughput since most of the incoming packets violate the delay threshold and thus discarded. The effect of delay threshold under different scheduling intervals is discussed.

5.1 MinPower EDF Performance under different Scheduling Intervals

5.1.1 Comparison results of EDF vs. MinPower EDF for Scheduling Interval=5ms

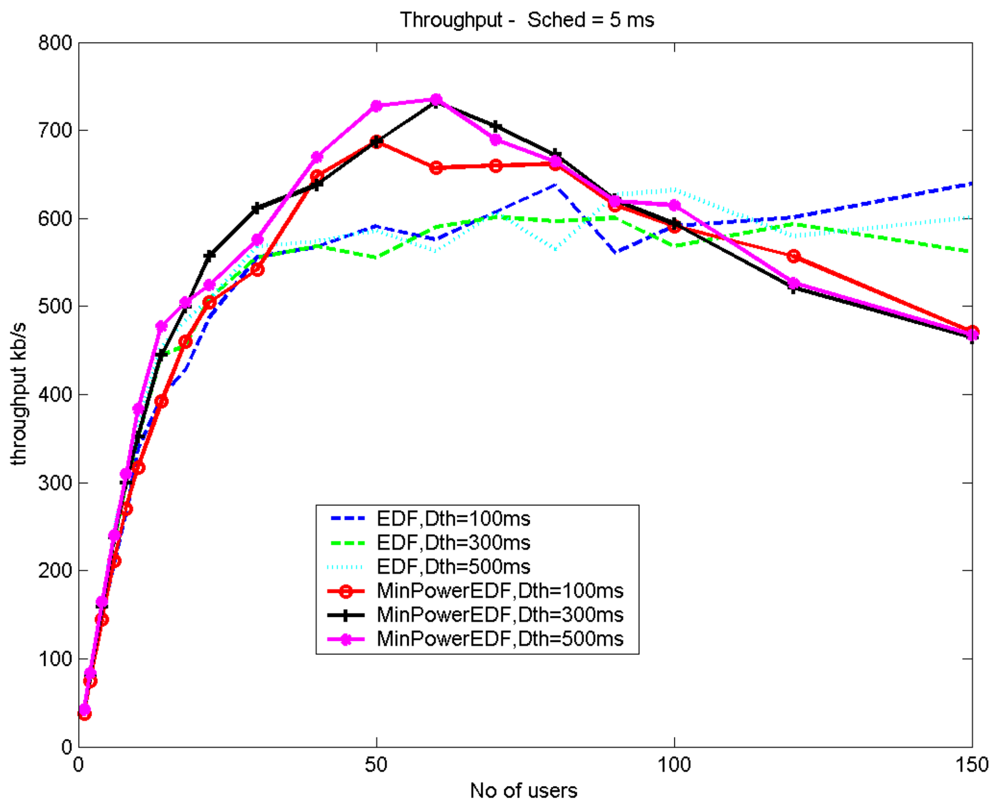

Figure 5.1: MinPower EDF Throughput vs. Offered load for sched=5ms

Figure 5.1 shows the comparison of throughput between EDF algorithm and MinPower EDF algorithm for the slot duration of 5ms and Delay threshold, D_{th}, constraint of 100ms, 300ms and 500ms respectively.

From the Figure 5.1 we can observe an increase in the throughput as the number of users increases and then stabilize attaining a maximum value of 600kbps for EDF algorithm.

Whereas in MinPower EDF algorithm, the throughput increases as the number of users increases upto 50 users achieving a maximum value of 750kb/s and then starts decreasing as offered load increases. This increase is higher than the EDF algorithm initially and then starts decreasing. This increase is because initially users are few and the packets corresponding to them are few. The slots in which these packets to be scheduled are more. Therefore, the packets are being scheduled even with higher packet size. Thus increasing the throughput until all slots are scheduled. After reaching its maximum capacity around 750kbps the throughput starts decreasing. This is because the proposed MinPower EDF algorithm is based on the minimum power packet. The transmission rate is a function of packet size, offered load and scheduling interval size. Since bit rate=packet size/Slot duration, it is clear that throughput is directly proportional to the packet size. This reduces the average bit rate, which in turn decreases throughput as number of users increases as shown in Figure 5.1. On the other hand, in case of EDF algorithm the throughput achieves its maximum and remains stable around 600kbps as the number of users increases. The sensitivity to the delay threshold is expected to be a function of the traffic generator statistics .The effect of delay threshold can be seen in the above Figure 5.1. A difference of 3% to 5% is observed for different delay thresholds on throughput for 40 users.

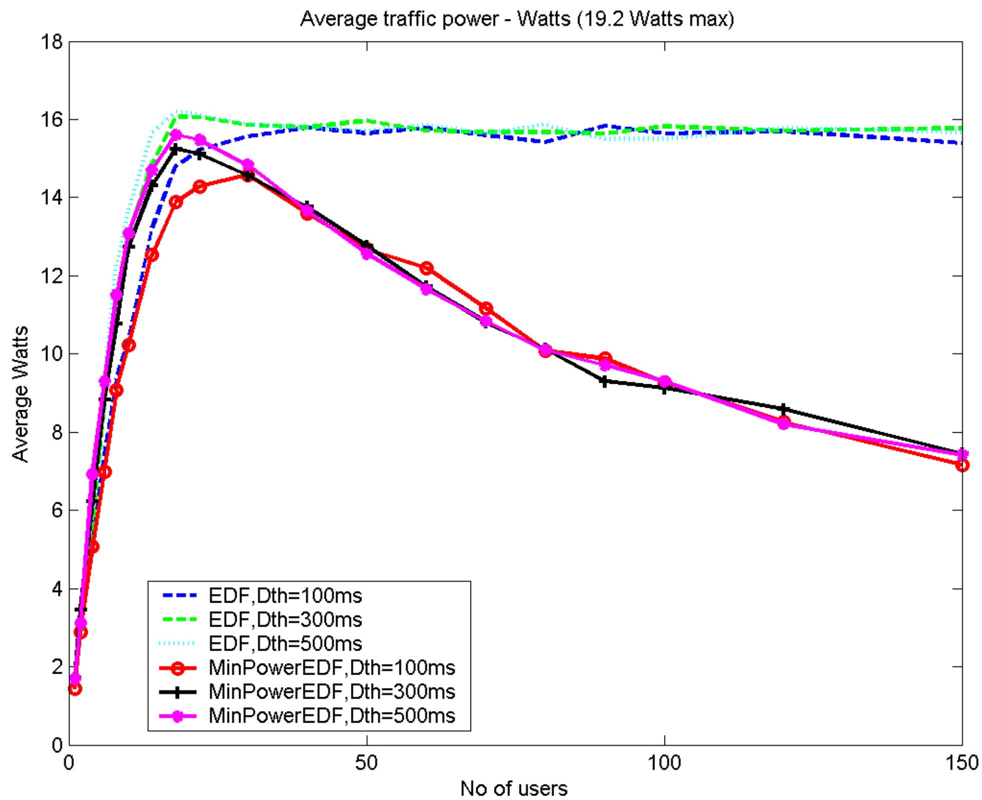

Figure 5.2: MinPower EDF Average Power vs. Offered load for sched=5ms

Figure 5.2 shows the average power against offered load for the slot duration of 5ms with delay thresholds ranging from 100ms, 300ms and 500ms respectively. Initially the average power increases as the number of users increases initially till maximum capacity is reached. We can observe a decrease before reaching the maximum capacity due to serving minimum power packets after certain users. On the other hand, EDF algorithm serves irrespective of power. Thus, the average power stabilizes. However, in the former case only the minimum power packet is served. Thus, the average power decreases as illustrated in Figure 5.2. For example, 50 users utilize average power of 16 watts in EDF algorithm compared to when Minimum power EDF algorithm utilizes around 13 watts.

As can be seen in Figure 5.3 CDF for 50 users that the packet size of MinPower EDF is less than that of EDF for 90% of time. This shows why the average power decreases as offered load increases due to the serving of less packet sizes.

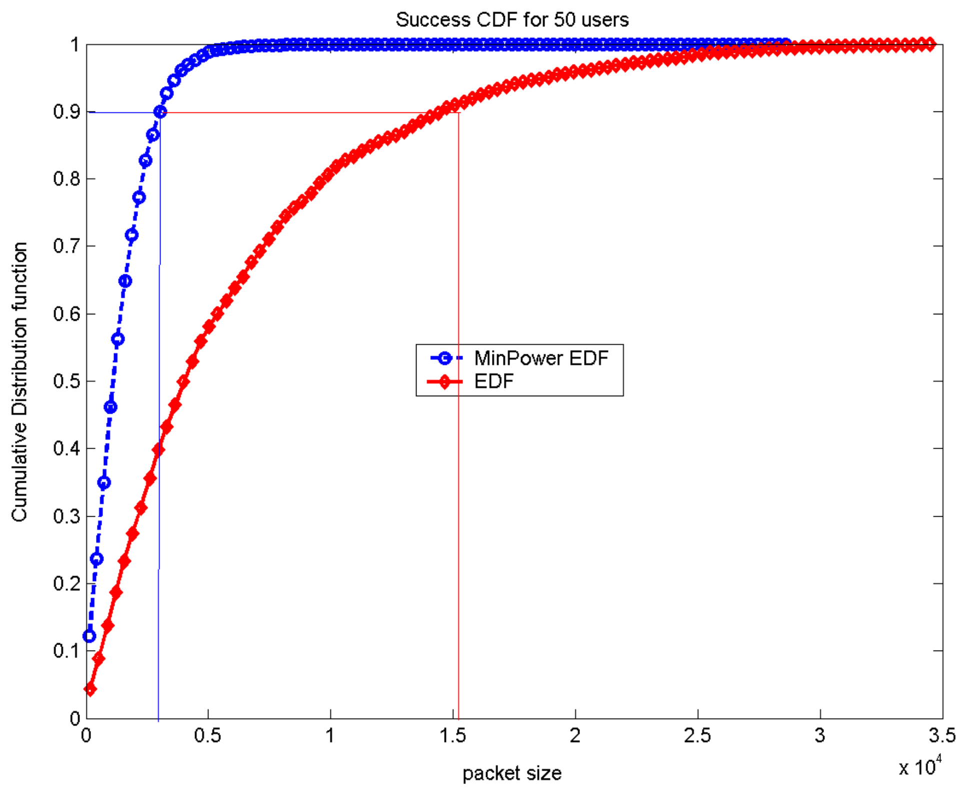

Figure 5.3: MinPower EDF Success CDF vs. packet size

Figure 5.3 shows that EDF is serving packets of size less than 15500 bits for 90% of the time whereas MinPower EDF is serving packets of size less than 3000 bits.

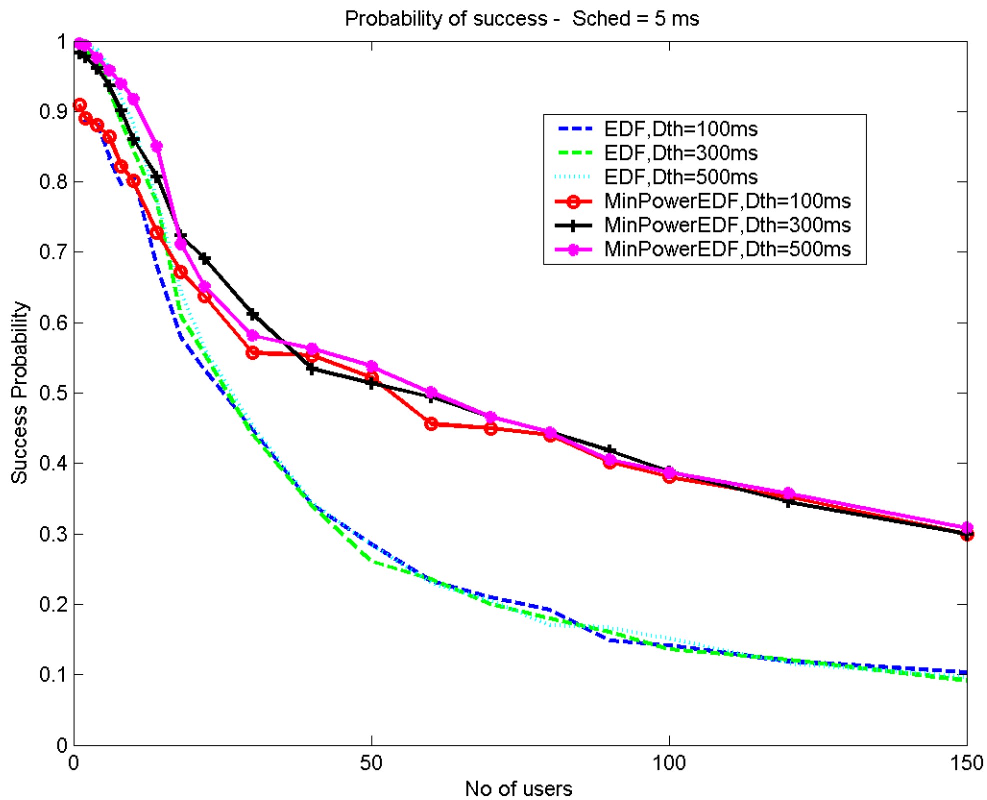

Figure 5.4: MinPower EDF Success Probability vs. Offered load for sched=5ms

Figure 5.4 presents the success probability against offered load for the slot duration of 5 ms with delay thresholds 100ms, 300ms and 500ms. The importance of this measure is that it shows the number of successfully transmitted packets. If success rate is more then the system is able to satisfy more number of users. The success rate of MinPower EDF is more when it is compared to the EDF algorithm. This shows that MinPower packets are served more than EDF algorithm that serves according to their deadlines. For example, the success rate for 150 users in MinPower EDF algorithm is approximately 30% when compared to EDF algorithm, which is hardly 10 %.

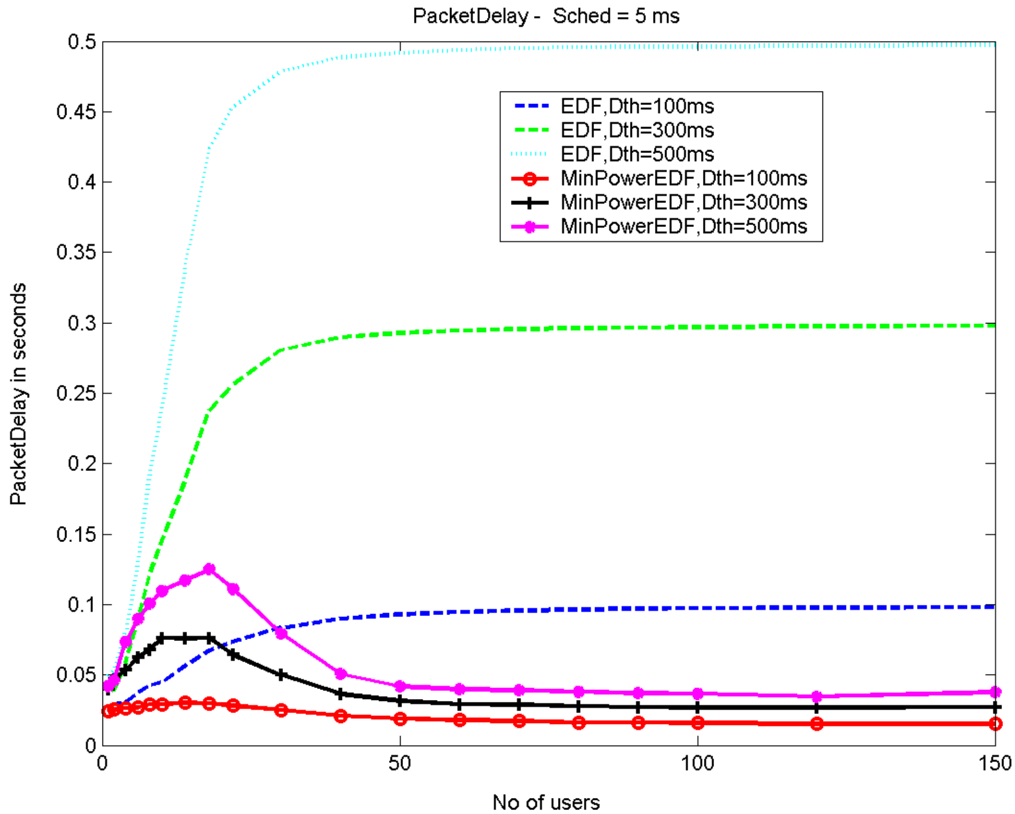

Figure 5.5 : MinPower EDF Packet Delay vs. Offered load for sched=5ms

Figure 5.5 shows the success packet delay vs. offered load for a scheduling interval of 5ms and delay thresholds ranging from 100ms, 300ms and 500ms. The success packet delays of MinPower EDF algorithm are 75% less than EDF algorithm because fresh packets are being served in that slot which is efficiently utilizing less power due to which interference is less. In EDF algorithm the packets are served according to their arrival times. Since the packets are less delayed the success rate is high in MinPower EDF algorithm. Due to Head of queue problem in EDF algorithm the delayed packets are getting discarded.

Table 5.1 summarizes the percentage comparison of throughput, average power and success probability between MinPower EDF and EDF at SI=5ms for the load of 50 users.

Table 5.1: Comparison of EDF vs. MinPower EDF at SI=5ms for 50 users

EDF vs. MinPower EDF (SI=5ms for 50 users)									
	Throughput (kbps)			Average Power (watts)			Success Probability		
Dth (ms)	EDF	MinPower EDF	%	EDF	MinPower EDF	%	EDF	MinPower EDF	%
100	580	680	17.2▲	15.7	13.6	13.3▼	0.28	0.53	89▲
300	550	680	23.63▲	15.6	13.7	12.1▼	0.27	0.52	92▲
500	570	720	26.31▲	15.5	13.8	10.9▼	0.27	0.55	103▲

5.1.2 Comparison results of EDF vs. MinPower EDF for Scheduling Interval=10ms

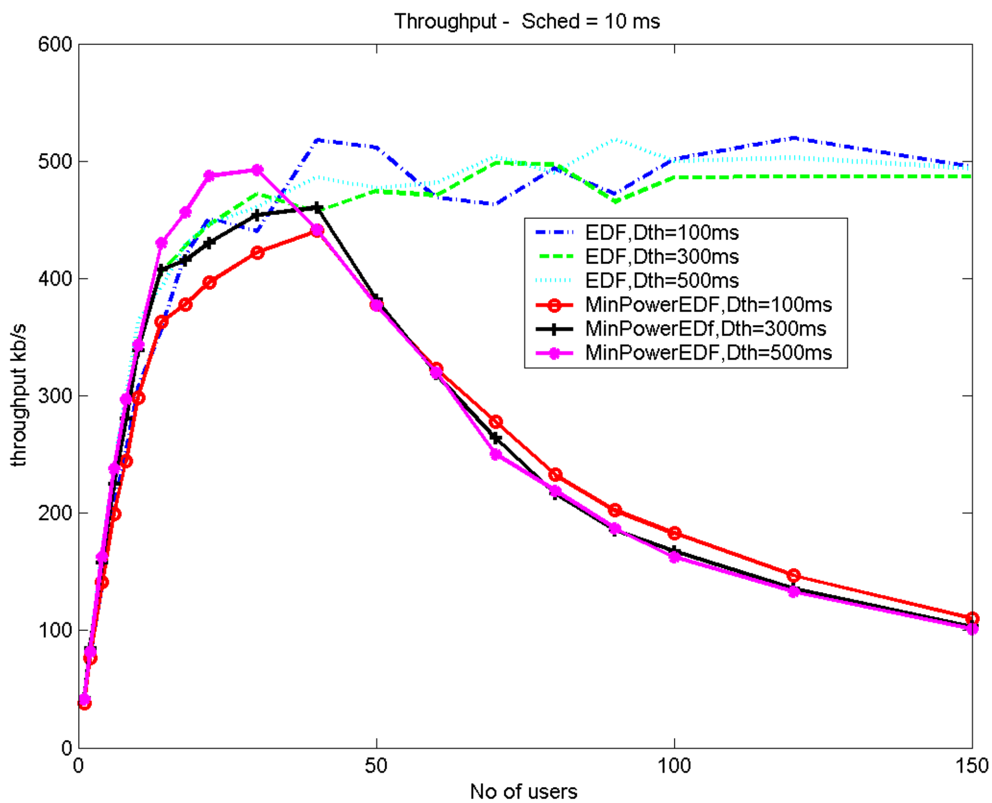

Figure 5.6: MinPower EDF Throughput vs. Offered load for sched=10ms

The Figure 5.6 demonstrates the throughput against offered load for a slot duration of 10ms with delay thresholds 100ms, 300ms and 500 ms. The throughput for MinPower EDF as shown in Figure 5.6 decreases as the number of users increases. This is because minimum power packet is served first, thus the minimum size packet to be served in the slot. The similar trend is observed as was seen in the previous section except that the magnitude of throughput is less (400kb/s) for 50 users. Beyond this value, the average bit rate decreases. This results in decrement in the throughput as the number of users increases. However, in the case of EDF algorithm it is getting stabilized as packets served according to arrival time irrespective of packet size. For example for 150 users, EDF is capable of achieving a maximum throughput of 500kb/s while maximum throughput for minimum power EDF is 100kb/s for the same networking parameters, showing 80%decrease in throughput.

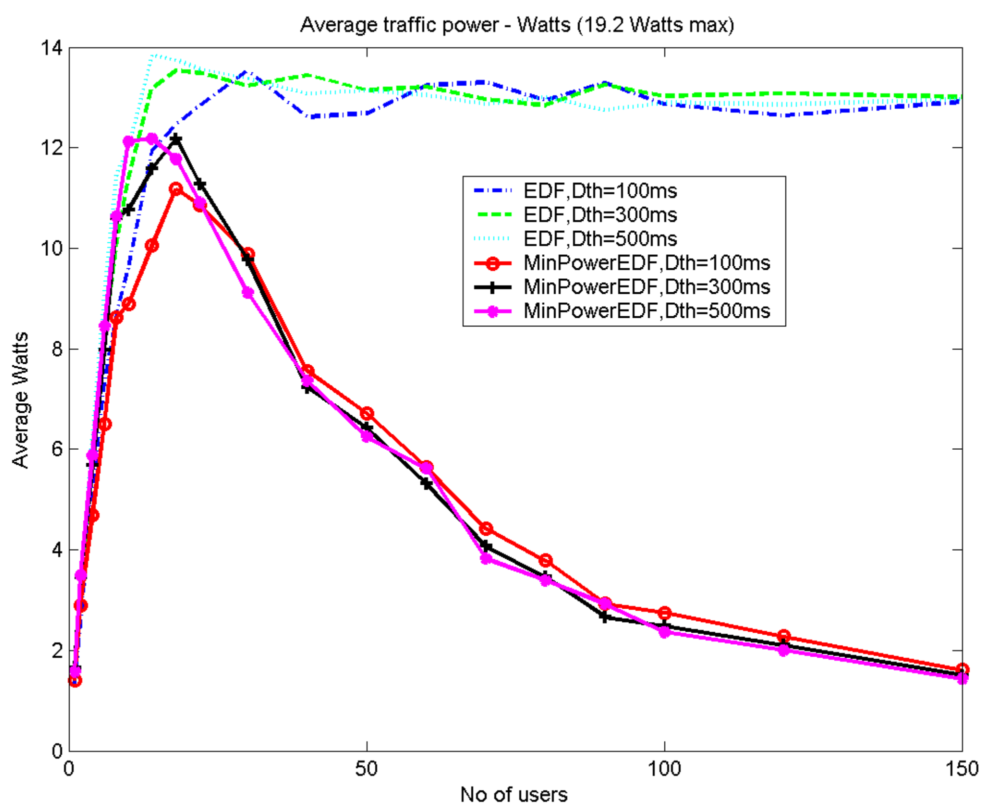

Figure 5.7: MinPower EDF Average Power vs. Offered load for sched=10ms

Figure 5.7 represents the average power against offered load for the slot duration of 10ms with delay thresholds ranging 100ms, 300 ms and 500ms. From Figure 5.7, it is clear that the average power increases as number of users increase and then decreases. This is due to minimum power packet is served in each slot in MinPower EDF, but in EDF the packet is served according to arrival time irrespective of power. The MinPower EDF utilizes less slot power thus saving large amount of power For example the average power utilization for 150 users is 14 watts when compared to the MinPower EDF algorithm, which utilizes less than 2 watts

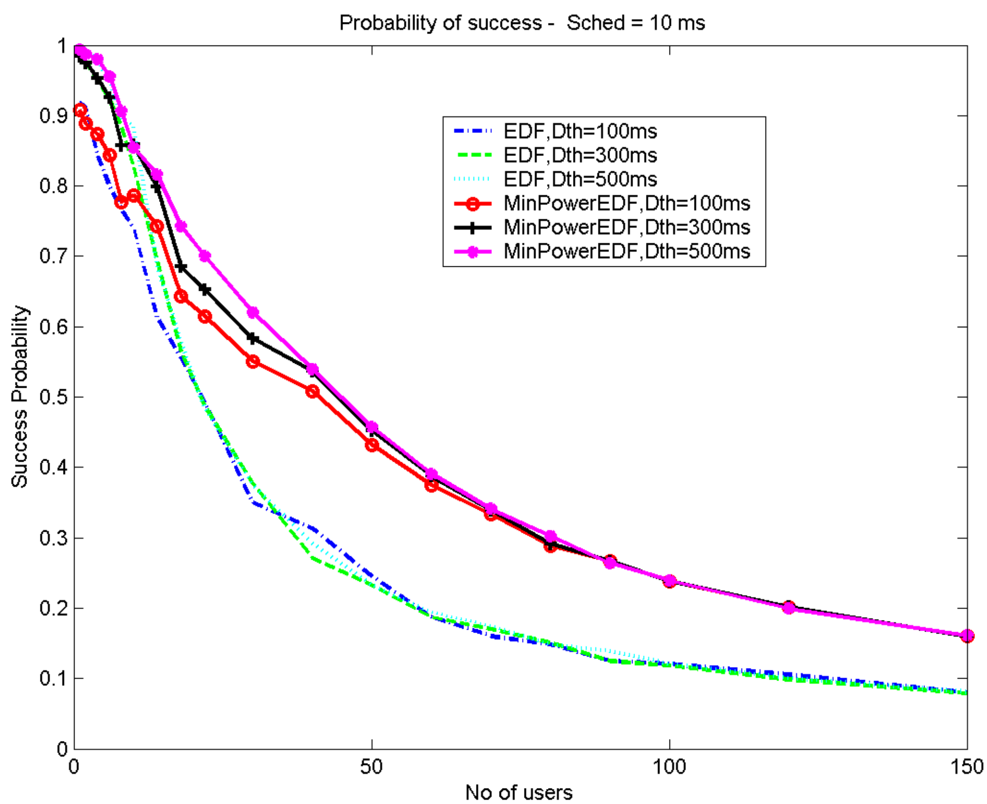

Figure 5.8: MinPower EDF Success Probability vs. Offered load for sched=10ms

Figure 5.8 demonstrates the Success rate plotted against offered load for scheduling Interval of 10ms with delay thresholds 100ms, 300ms and 500ms.The success rate of

MinPower EDF algorithm can achieve higher levels when compared to the EDF algorithm. This shows that MinPower packets are served as their delays are within the threshold. The reason behind this is that all the arrivals happening in the previous slots are also being served in the slots unlike EDF, which serves according to the FCFS. The success rate for 50 users reaches around 40% in MinPower EDF algorithm when compared to EDF algorithm, which could hardly serve 20%. The success rate is almost double in case of MinPower EDF algorithm. The success rate is more but the throughput is less for the scheduling interval of 10ms as the packets are being served according to MinPower, which utilizes minimum size packet, but success rate is high as there is no head of queue problem in MinPower EDF unlike EDF that suffers low success rate due to head of queue problem.

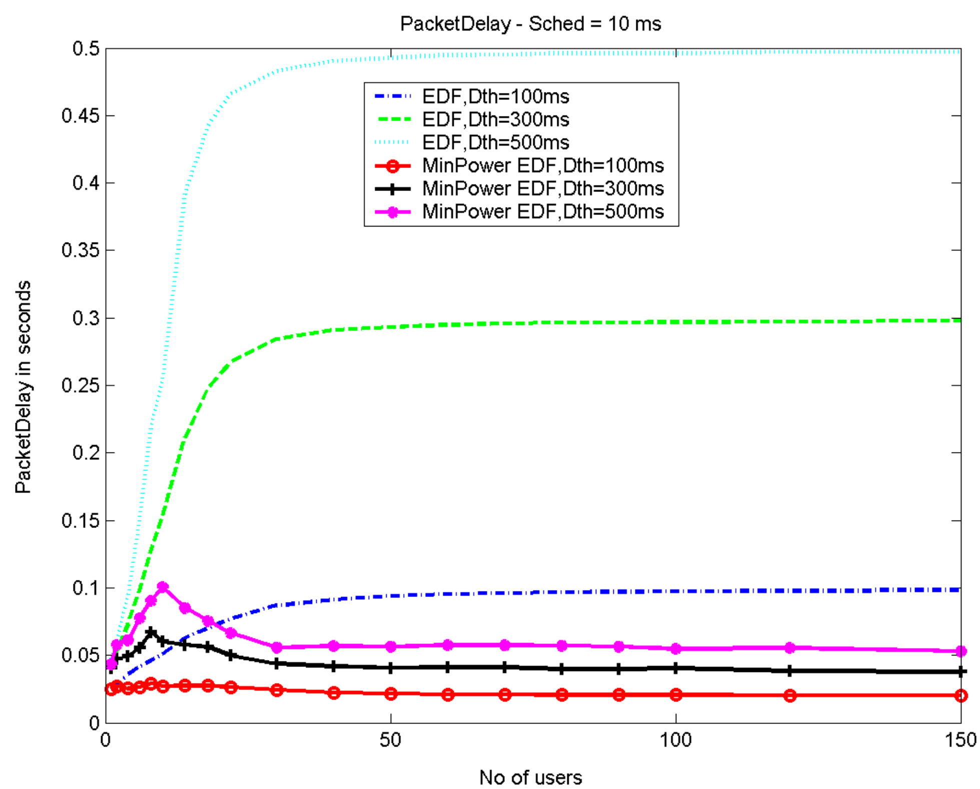

Figure 5.9: MinPower EDF Packet Delay vs. Offered load for sched=10ms

Figure 5.9 shows the packet delay vs. offered load for a scheduling interval of 10ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MinPower EDF algorithm are 80% less than EDF algorithm because fresh packets are being served in that slot which is utilizing less power due to which interference is less. Table 5.2 summarizes the percentage comparison of throughput, average power and success probability between MinPower EDF and EDF at SI=10ms for the load of 50 users.

Table 5.2: Comparison of EDF vs. MinPower EDF at SI=10ms for 50 users

EDF vs. MinPower EDF (SI=10ms for 50 users)									
	Throughput (kbps)			Average Power (watts)			Success Probability		
Dth (ms)	EDF	MinPower EDF	%	EDF	MinPower EDF	%	EDF	MinPower EDF	%
100	500	380	24▼	12.5	6.8	45.6▼	0.25	0.43	72▲
300	483	380	21.3▼	12.8	6.3	50.7▼	0.24	0.44	83.3▲
500	480	380	20.83▼	12.8	6.2	51.5▼	0.23	0.45	95.6▲

5.1.3 Comparison results of EDF vs. MinPower EDF for Scheduling Interval=20ms

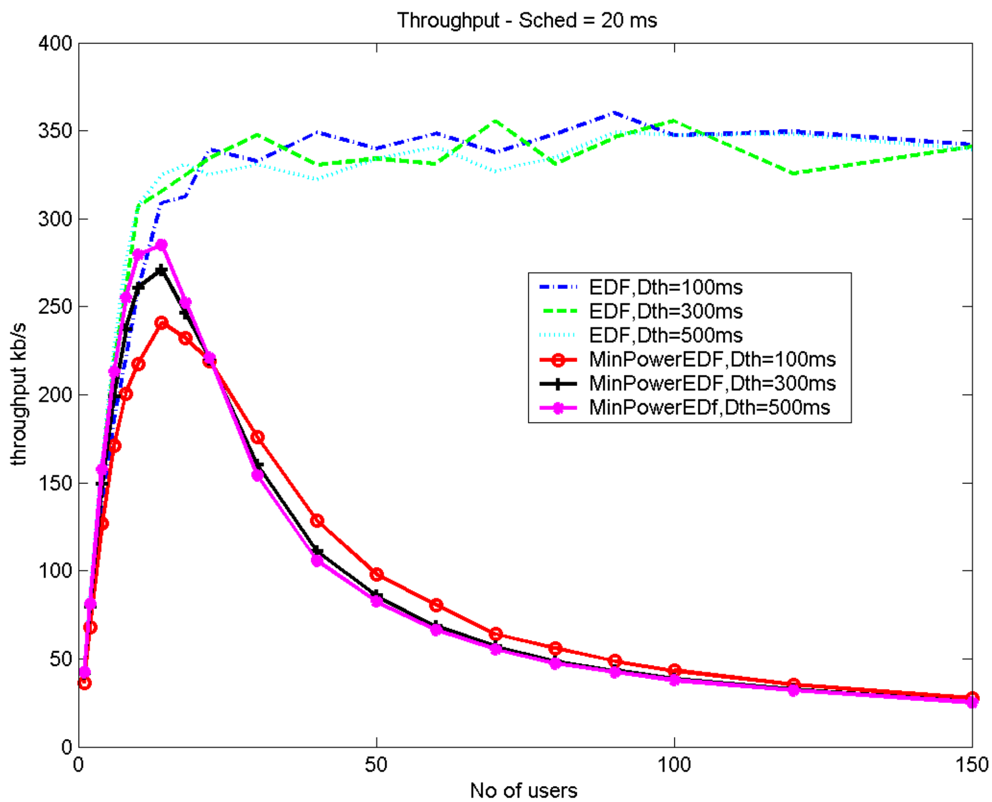

Figure 5.10: MinPower EDF Throughput vs. Offered load for sched=20ms

Figure 5.10 demonstrates the throughput i.e. average bit rate against the offered load. This average bit rate is calculated using continuous bit rate. The bit rate calculated using the packet size of each packet against the scheduling interval. Thus, the throughput is directly proportional to the packet size. Thus, the throughput decreases in MinPower EDF because at high load more of smaller packets are served. In EDF algorithm, the packet is chosen according to the arrival time irrespective of packet size. This is the reason of the average rate getting stabilized in the case of EDF as against our proposed algorithm. For example, EDF algorithm is able to achieve the throughput of 350kb/s for 150 users when compared to MinPower EDF algorithm, which achieves the throughput of 50 kb/s.

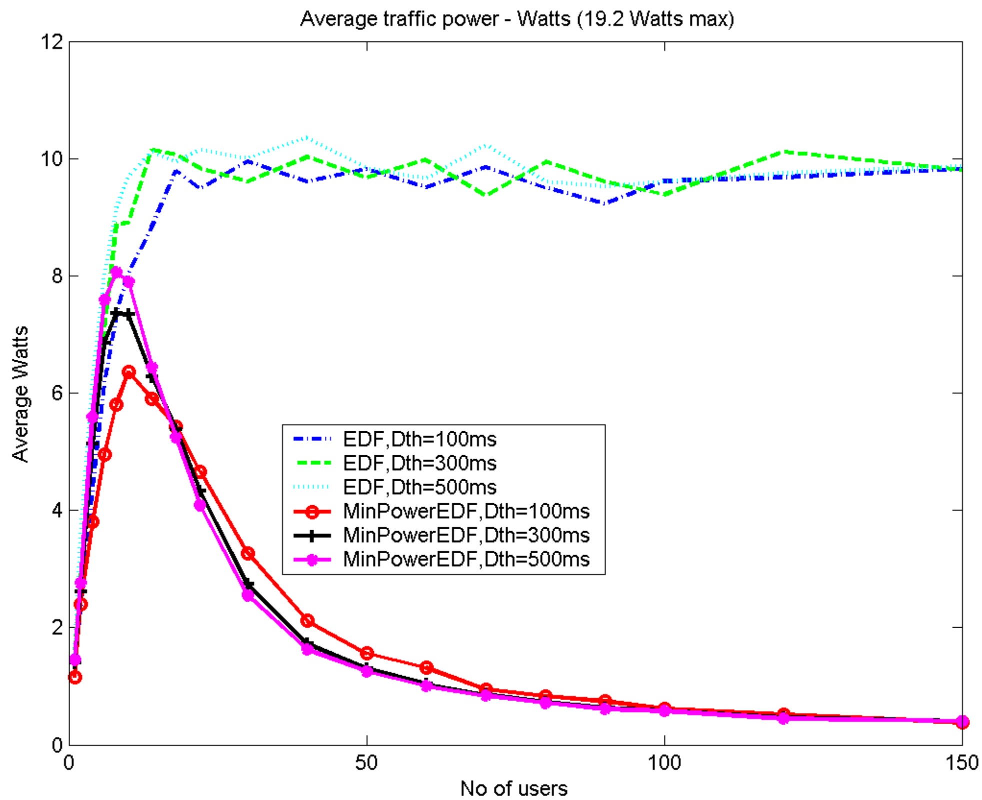

Figure 5.11: MinPower EDF Average Power vs. Offered load for sched=20ms

Figure 5.11 shows the average traffic power against the offered load. Each user cannot use more than the maximum power at any given time. The power usage is less in MinPower EDF, thus saving the power for any other usage. The EDF algorithm uses more power than our proposed algorithm.

As the number of users increases average power increases and then decreases as the minimum power packet is served in each slot unlike EDF, which serves based on the arrival time. In EDF, the average power increases and becomes constant, as the average of all powers remains constant. For example, 150 users utilize around 10 watts average power in EDF algorithm when compared to MinPower EDF algorithm that utilizes only 1 watt of power.

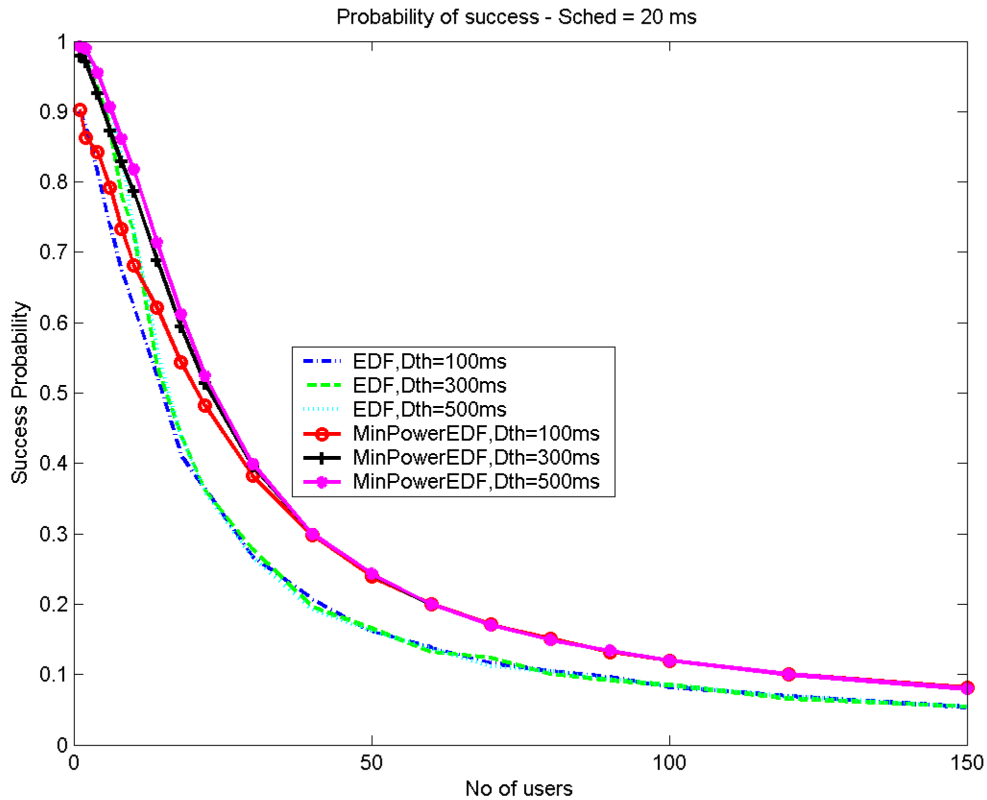

Figure 5.12: MinPower EDF Success Probability vs. Offered load for sched=20ms

Figure 5.12 shows the probability of successful transmission against offered load. It is clearly indicated in the Figure 5.12 that the MinPower EDF packet has larger success rate than the EDF success rate as all the packets are being served. This shows that Minimum power packets are served as their delays are within the threshold whereas in EDF the arrivals are getting discarded due to head of queue problem. For example, at 50 user load the success rate of MinPower EDF algorithm is able to serve 25% of the load whereas EDF algorithm is able to serve only 15%.

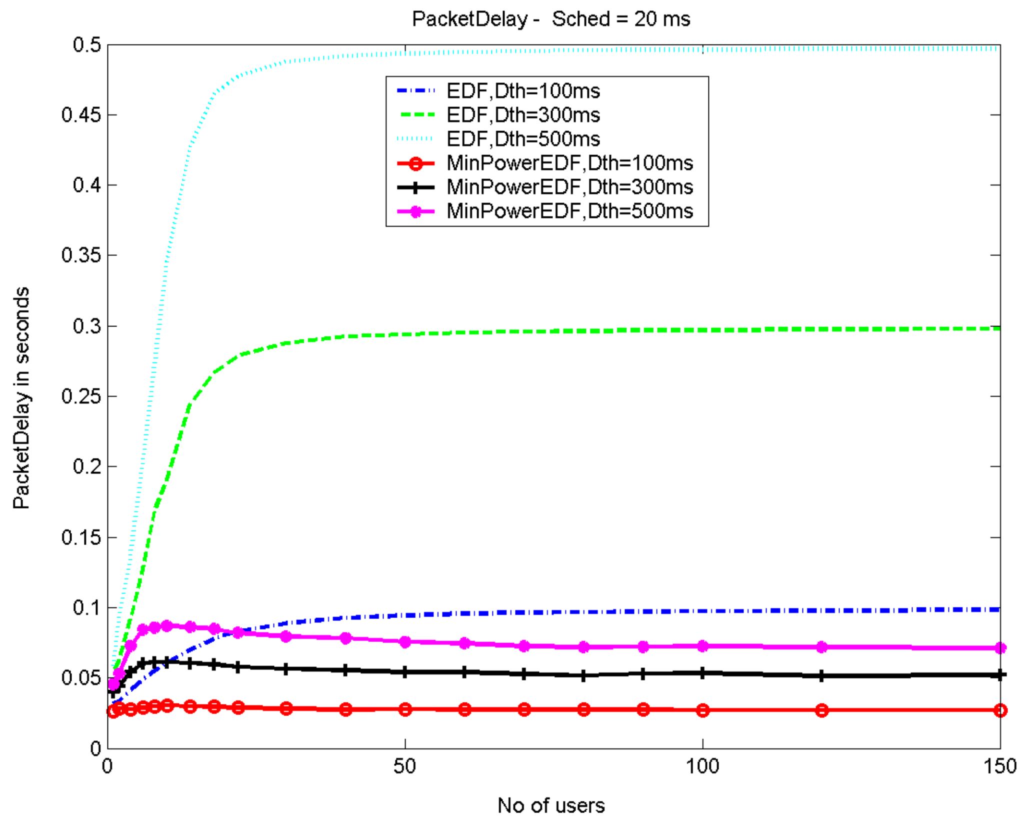

Figure 5.13: MinPower EDF Packet Delay vs. Offered load for sched=20ms

Figure 5.13 shows the packet delay vs. offered load for a scheduling interval of 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MinPower EDF algorithm are 84% less than EDF algorithm because fresh packets are being served in that slot which is utilizing less power due to which interference is less. In EDF algorithm the packets are served according to their arrival times.

Table 5.3 summarizes the percentage comparison of throughput, average power and success probability between MinPower EDF and EDF at SI=20ms for the load of 50 users.

Table 5.3: Comparison of EDF vs. MinPower EDF at SI=20ms for 50 users

EDF vs. MinPower EDF (SI=20ms for 50 users)									
	Throughput (kbps)			Average Power (watts)			Success Probability		
Dth (ms)	EDF	MinPower EDF	%	EDF	MinPower EDF	%	EDF	MinPower EDF	%
100	340	100	70.5▼	9.8	1.5	84.6▼	0.14	0.25	78.5▲
300	336	91	72.91▼	9.7	1.4	85.5▼	0.13	0.24	84.6▲
500	335	90	73.13▼	9.6	1.3	86.4▼	0.12	0.24	100▲

5.2 Effect of Scheduling Interval on MinPower EDF

Scheduling Interval (SI) is defined as the interval during which the packets are scheduled in the slots at base station. This scheduling interval varies from 5ms -20ms to see the effect on throughput, power, success rate. As SI increases the throughput decreases since bit rate is inversely proportional to the SI. As SI increases number of arrivals increase thus the chance of selecting MinPower packet increases as SI increases.

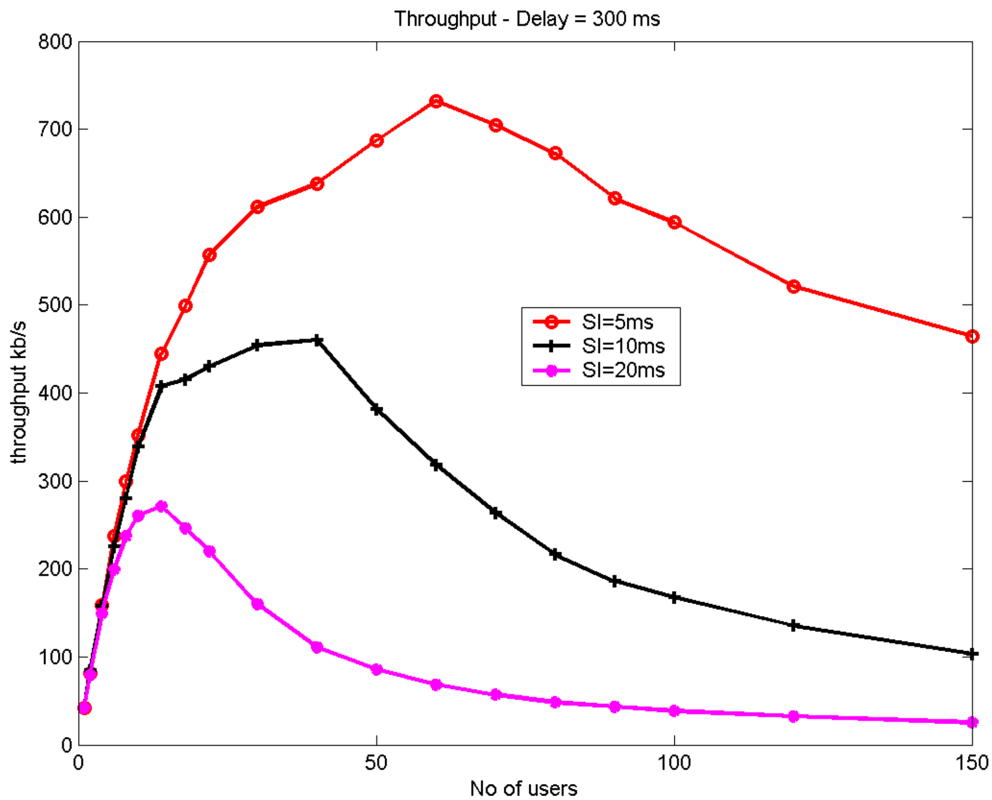

Figure 5.14: MinPower EDF Throughput vs. offered load for SI=5, 10, 20 ms and Dth=300ms

Figure 5.14 shows the throughput vs. offered load for different scheduling intervals at a particular delay threshold of 300ms. The above Figure 5.14 shows that as scheduling Interval increases the throughput decreases since throughput is inversely proportional to the scheduling interval. Thus, the results of throughput when scheduling interval is 5ms for 60 users is around 700kbps very high i.e., the bit rate is good for more number of users but when the scheduling interval increases to 10ms and 20ms it decreases to around 350kbps and 50kbps respectively i.e. bit rate decreases for more offered load. This shows that slot duration plays an important role in supporting good bit rate for the offered load.

The increase in the slot duration facilitates the increase in the number of arrivals hence the chance of selecting minimum power packet increases as the scheduling interval increases thus decreasing the throughput.

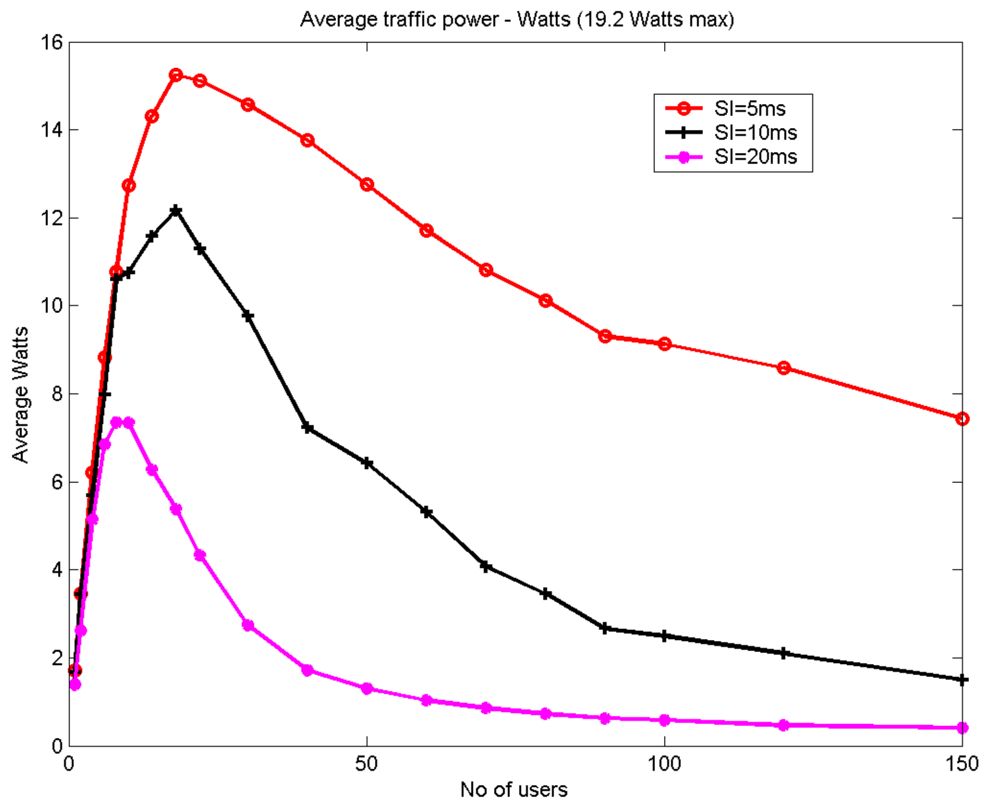

Figure 5.15: MinPower EDF Average Power vs. offered load for SI=5, 10, 20 ms and Dth=300ms

Figure 5.15 shows the average power vs. offered load for different scheduling intervals and a particular delay threshold of 300ms. The power is utilized more around 13 watts when the scheduling interval is less ie.5ms for 50 users. When the Scheduling Interval increases from 10ms to 20ms the average power gradually decreases to around 6watts and 1.5 watts respectively for 50 users, thus saving slot power.

For the load of 150 users when SI is 5ms the throughput/watt is around 62.66 b/s/w, as SI increases to 10ms the bit rate/watt is around 61.11 b/s/w. For SI=20ms the bit rate/watt decreases to 42.85 b/s/w.

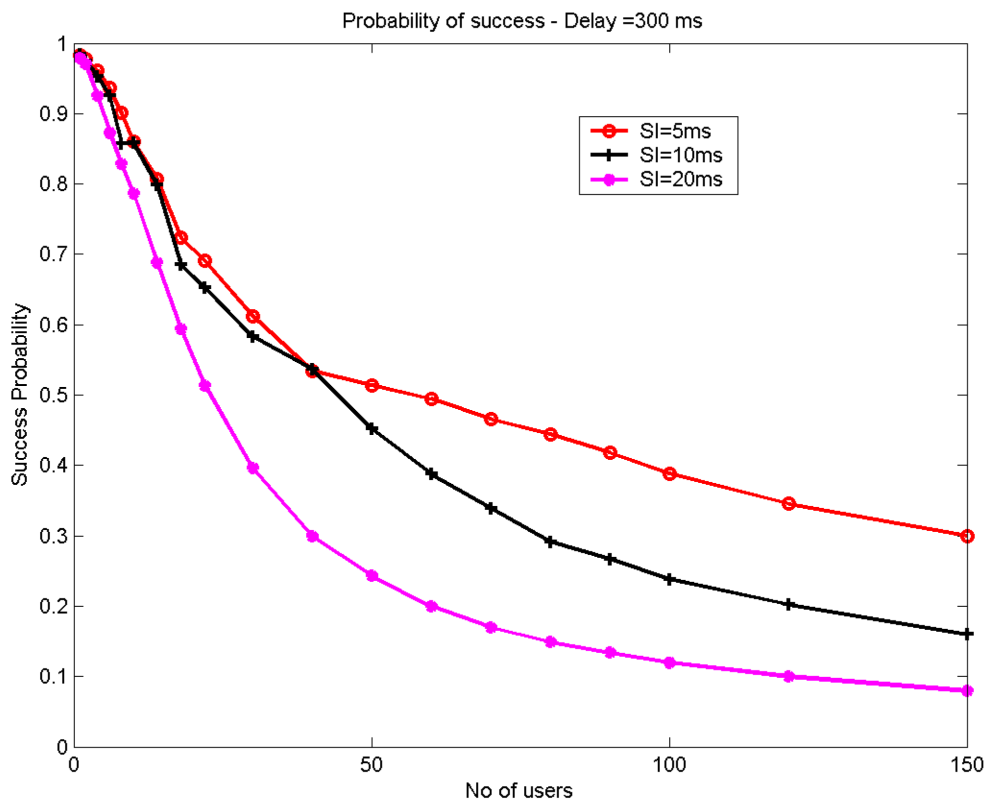

Figure 5.16: MinPower EDF Success Prob. vs. offered load for SI=5, 10, 20 ms and Dth=300ms

Figure 5.16 illustrates the success probability vs. offered load for different scheduling intervals and at a particular delay threshold of 300ms.The success rate for the scheduling interval of 5ms is around 40 % for 80 users thus serving more number of users in the system. It can be observed from the Figure 5.16 that as the Scheduling interval increases from 10ms to 20ms, then the success rate gradually decreases to 30% and 15% respectively. The arrivals happening in the 5ms-scheduling interval is less so they are being served faster due to less packet delays since they are less delayed thus serving more packets in this scheduling interval. On the other hand, as the scheduling interval increases the arrivals accumulating in that slot duration increases. This has an effect on increasing the packet delays and results in more number of packets discarded due to the restriction of delay threshold as shown in Figure 5.17.

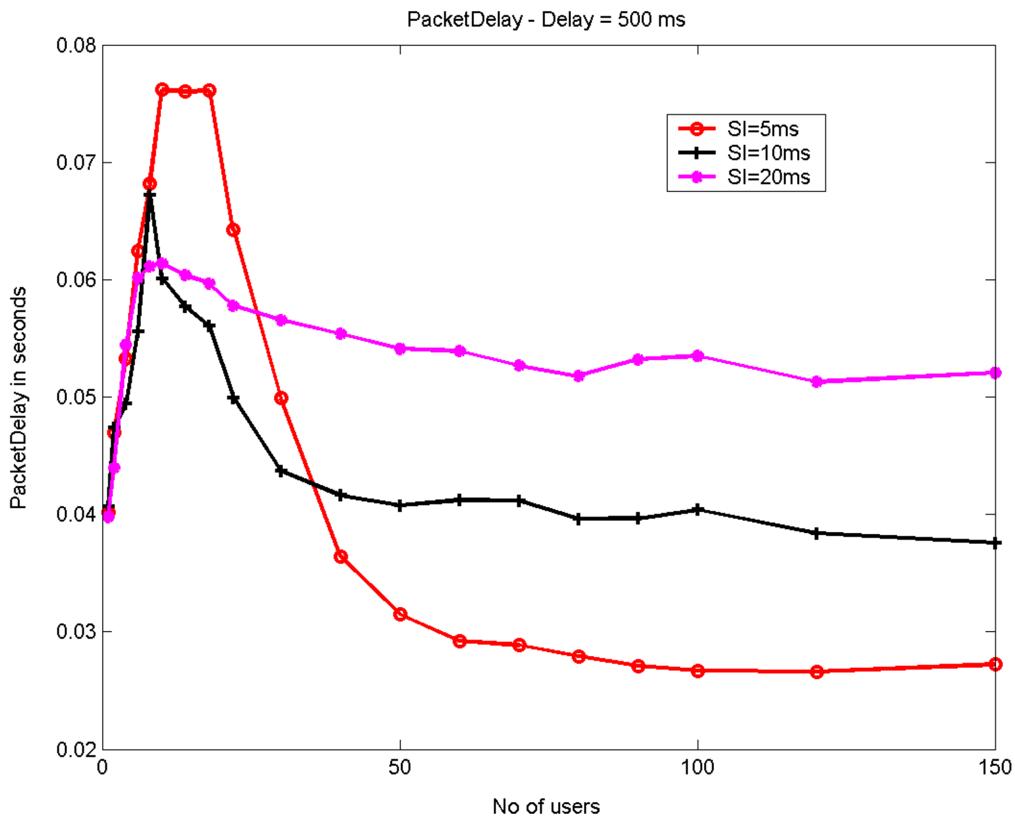

Figure 5.17: MinPower EDF Packet Delay. Vs. offered load for SI=5, 10, 20 ms and Dth=300ms

Figure 5.17 shows the packet delay vs. offered load for scheduling intervals of 5ms, 10ms and 20ms with a delay threshold of 300ms. The packet delays of MinPower EDF algorithm increases as scheduling interval increases from 5ms to 20ms.

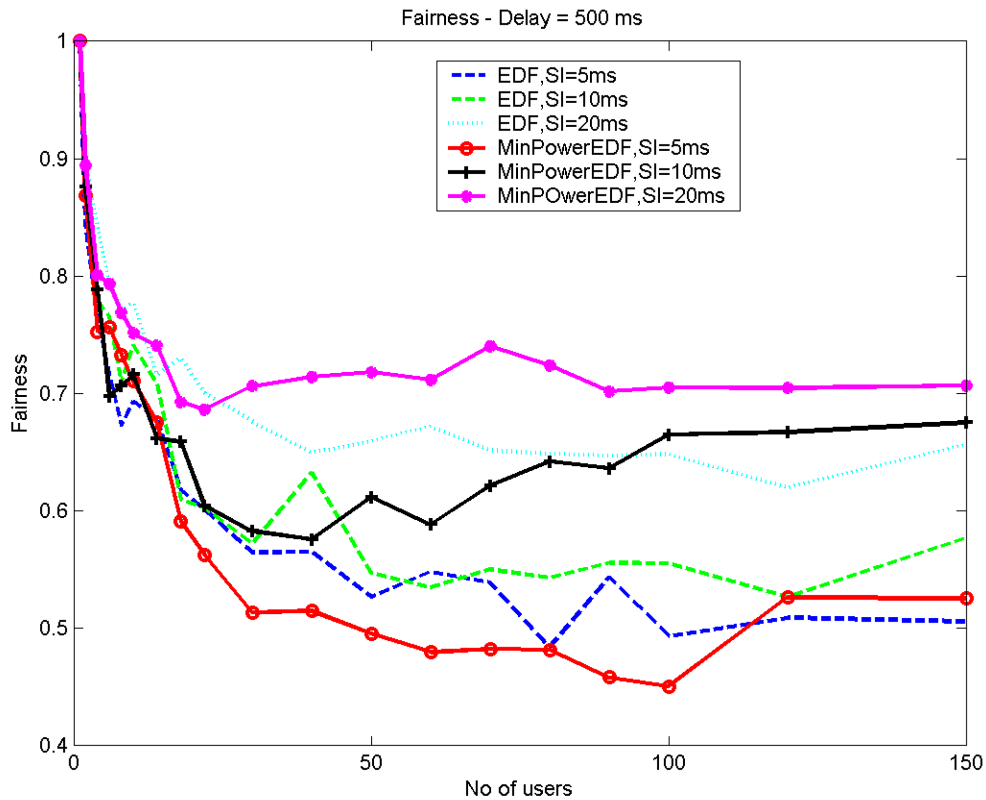

Figure 5.18: Fairness vs. offered load for SI=5, 10, 20 ms and Dth=500ms

Finally, Figure 5.18 shows the fairness vs. offered load for scheduling intervals 5ms, 10ms and 20ms with a delay threshold 500ms. The fairness of MinPower EDF algorithm increases as scheduling interval increases from 5ms to 20ms. The fairness for the load of 150 users at SI=20ms is around 71% for MinPower EDF whereas the fairness for EDF is around 53% for the same offered load.

In EDF, the head-of-queue (HOQ) packet of each queue is compared to determine which comes first and is scheduled according to earliest deadline. This order is fixed, and if a connection goes into bad state it will have to wait until it comes out of bad state and the other HOQ packets are served first. The second packet in the same queue faces the same challenge. Thus making users to starve till the connection changes to good state.

MinPower EDF is better as the packets are sorted in every slot. Hence if the connection goes in a bad state, in the next a slot the next user packet may get scheduled because of minimum power.

5.3 MinPower PEDF Performance under different Scheduling Intervals

5.3.1 Comparison results of PEDF vs. MinPower PEDF for Scheduling Interval=5ms

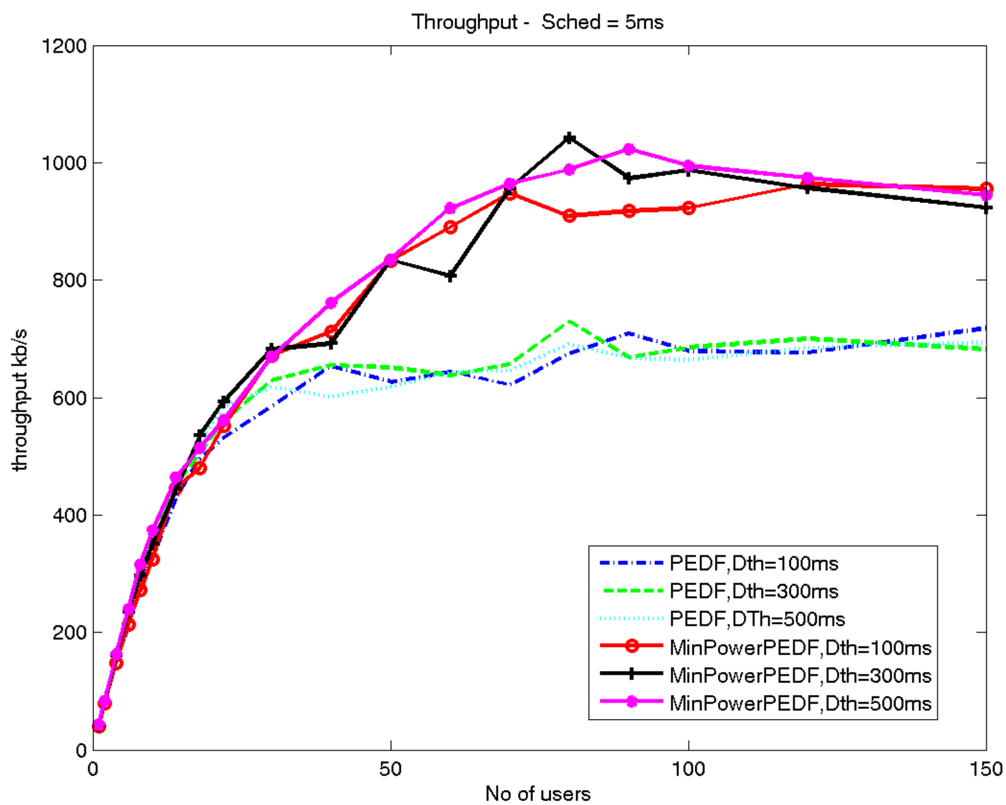

Figure 5.19: MinPower PEDF Throughput vs. Offered load for sched=5ms

Figure 5.19 demonstrates the plot of throughput against offered load. The throughput of MinPower PEDF algorithm is better than PEDF algorithm for the slot duration of 5ms. The throughput is stabilized around 600kbps in PEDF. When compared to PEDF the throughput of MinPower PEDF is higher with an increase in throughput for more than 200kbps at 100 users load. The trend is the same as PEDF algorithm.

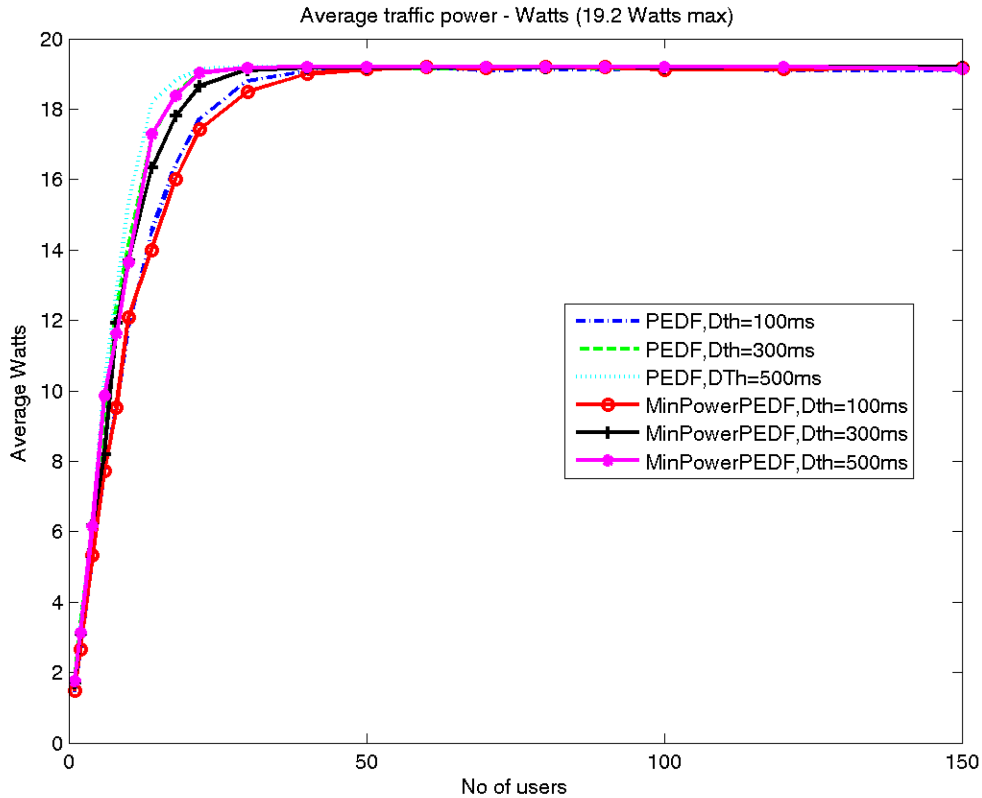

Figure 5.20: MinPower PEDF Average Power vs. Offered load for sched=5ms

Figure 5.20 shows the average traffic power against the offered load. The average traffic power increases as the offered load increases and becomes stable. The plot for average power in both PEDF and MinPower PEDF is the same as total slot power is utilized to serve the multiple packets.

As the delay threshold increases the power utilization also increases at the load of 30 users. As the delay threshold increases more packets are served therefore require more power.

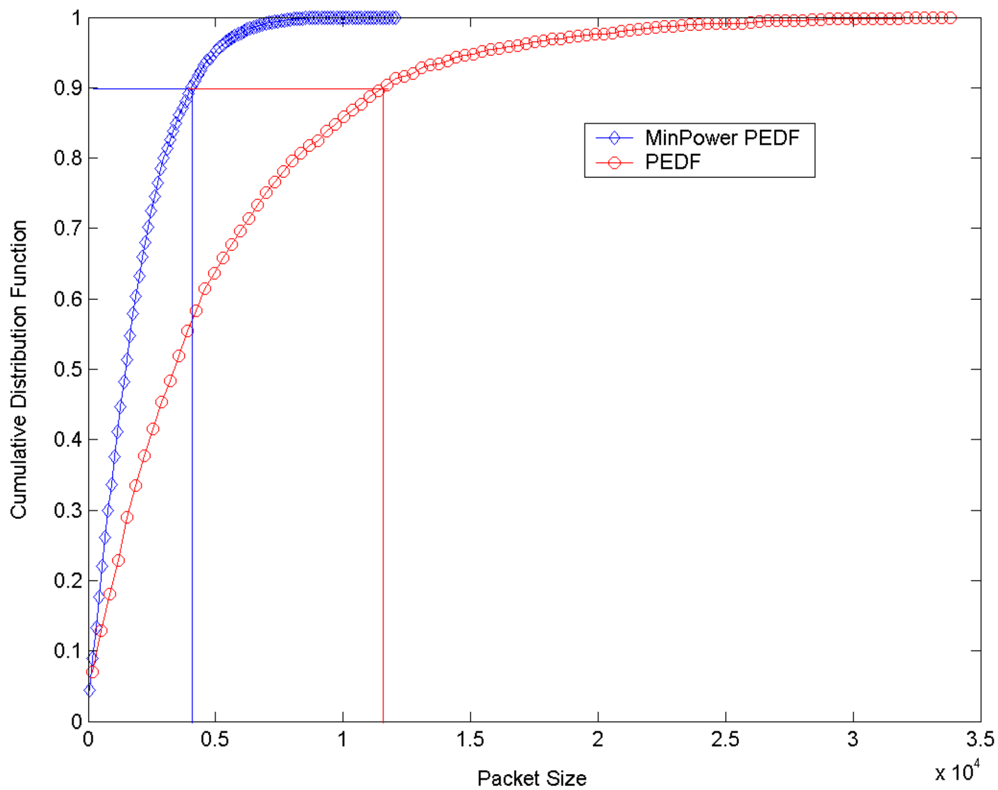

Figure 5.21: MinPower PEDF Success CDF vs packet size

Figure 5.21 demonstrates the CDF for PEDF and MinPower PEDF for 120 users. It is clear from the Figure 5.21 that 90% of the time PEDF is serving packet of size less than 12000 bits whereas MinPower PEDF is serving packet of size less than 3500 bits. This finding explains the drop in throughput as load increases.

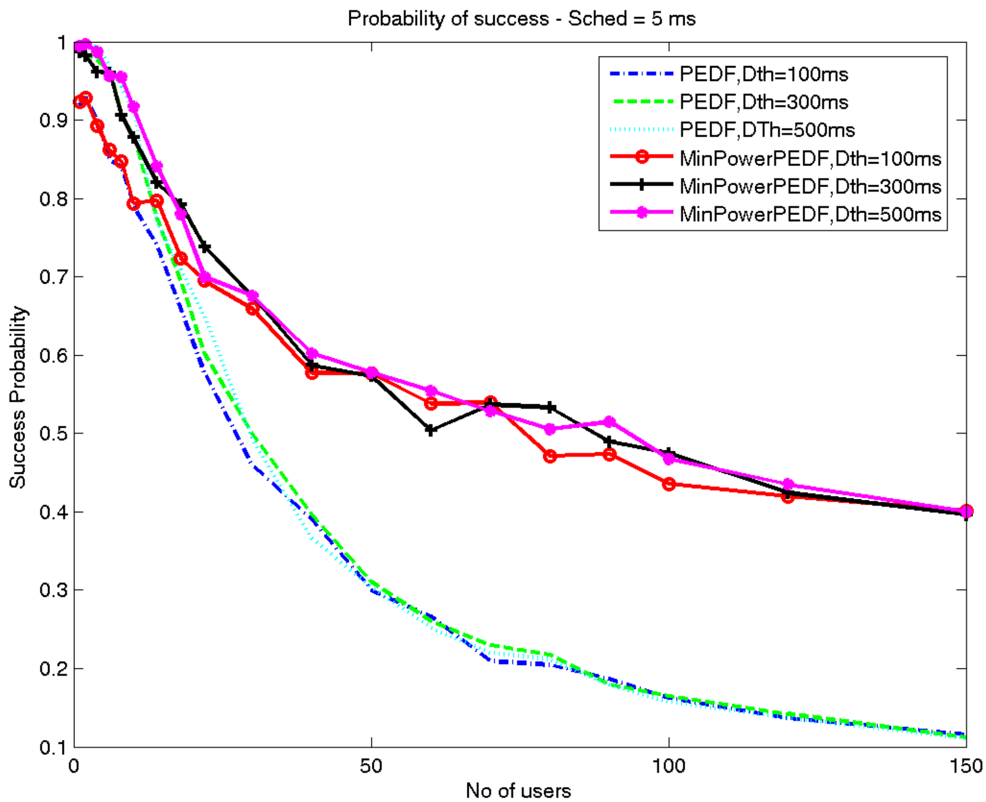

Figure 5.22: MinPower PEDF Success Probability vs. Offered load for Sched=5ms

Figure 5.22 depicts the success rate against the offered load. As shown in Figure 5.22 the success rate is more in MinPower PEDF algorithm than PEDF algorithm. MinPower PEDF serves the minimum power packet thus accommodating more packets than PEDF. In PEDF, the packets are served according to their deadlines. Thus the success rate per slot is more than the PEDF. The reason behind this increase in success rate is more number of minimum power packets are being served in each slot as the minimum power packets take minimum size packet.

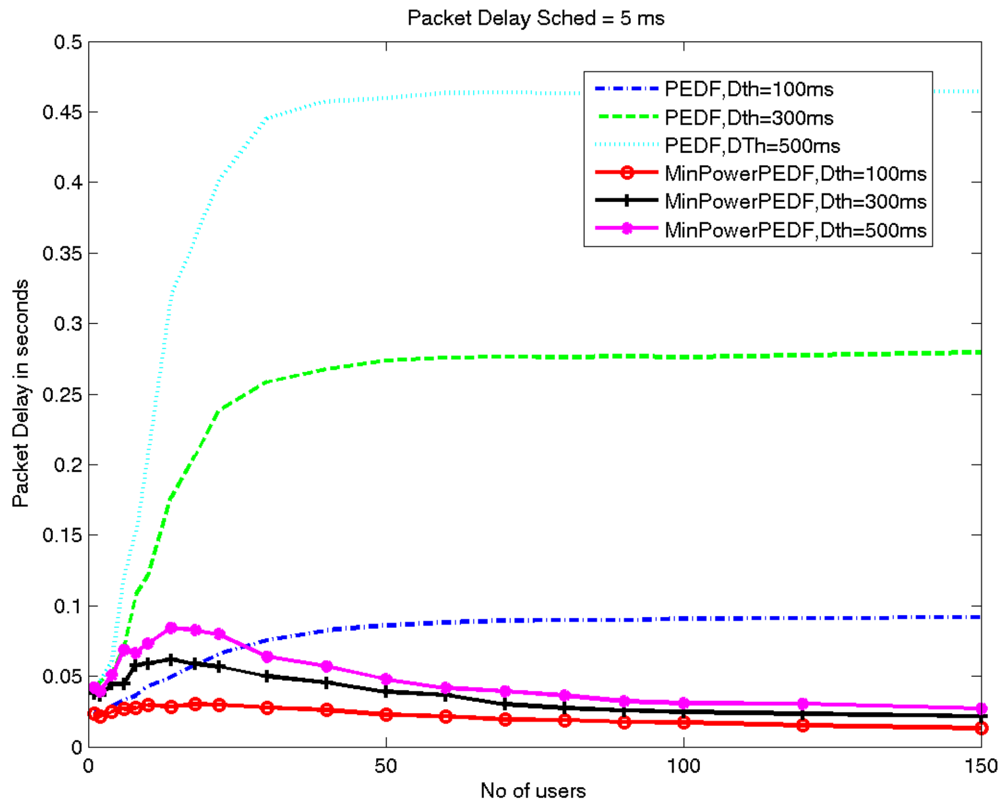

Figure 5.23: MinPower PEDF Packet Delay vs. Offered load for Sched=5ms

Figure 5.23 shows the packet delay vs. offered load for a scheduling interval of 5ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MinPower PEDF algorithm are 82.2% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm, the packets are served according to their arrival times.

Table 5.4 summarizes the percentage comparison of throughput, average power and success probability between MinPower PEDF and PEDF at SI=5ms for the load of 50 users.

Table 5.4: Comparison of PEDF vs. MinPower PEDF at SI=5ms for 50 users

PEDF vs. MinPower PEDF (SI=5ms for 50 users)							
	Throughput (kbps)			Average Power (watts)	Success Probability		
Dth(ms)	PEDF	MinPower PEDF	%	Total slot power is utilized in both algorithms	PEDF	MinPower PEDF	%
100	620	820	32.2▲		0.31	0.58	87.09▲
300	650	819	26▲		0.30	0.57	90▲
500	610	818	34.09▲		0.29	0.57	96.5▲

5.3.2 Comparative results of PEDF vs. MinPower PEDF for Scheduling Interval=10ms

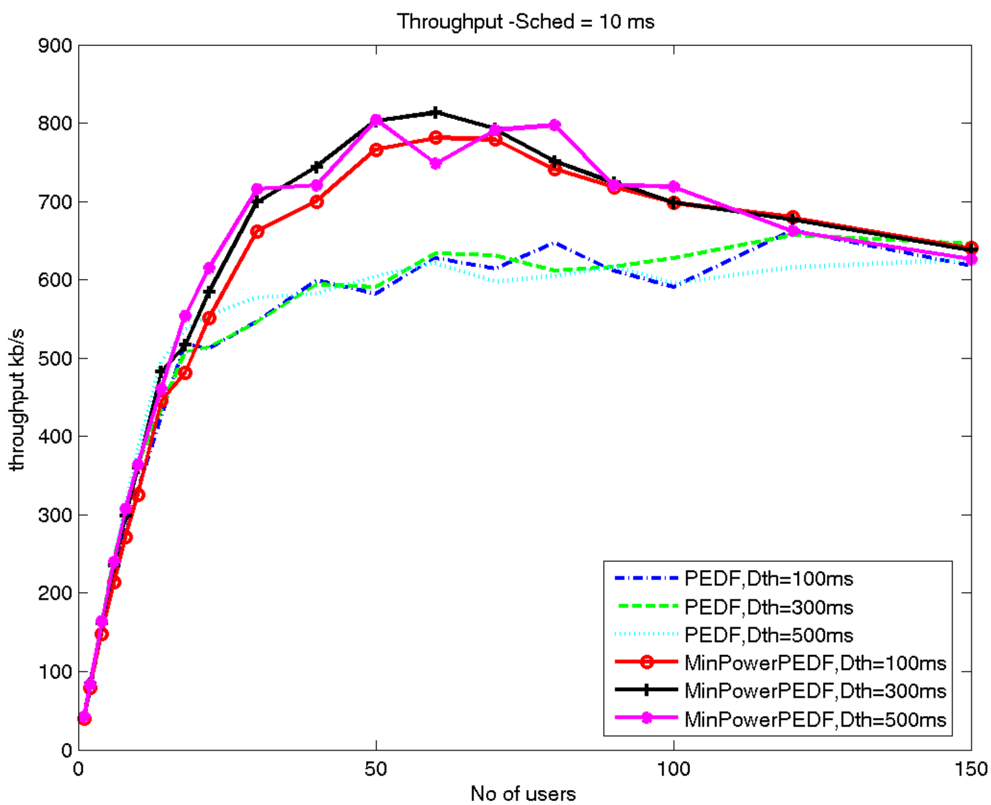

Figure 5.24: MinPower PEDF Throughput vs. Offered load for sched=10ms

Figure 5.24 shows the throughput against offered load for a scheduling interval of 10ms with delay thresholds 100ms, 300ms and 500ms.The throughput of MinPower PEDF increases as the offered load increases .It reaches to its maximum capacity and then starts decreasing. Since multiple minimum size packets are being served the throughput increases initially to around 800kbps. As the offered load increases the throughput starts decreasing and reaches around 600kbps for 150 users. As the offered load increases the success rate decreases thus decreasing the throughput.

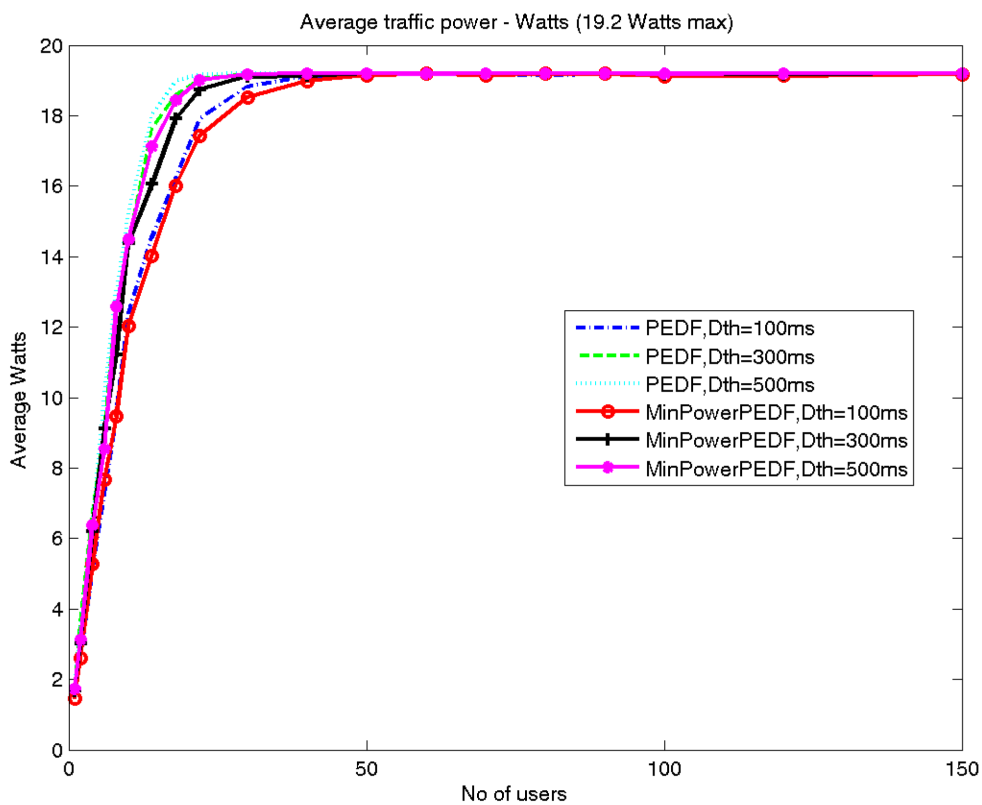

Figure 5.25: MinPower PEDF Average Power vs. Offered load for sched=10ms

Figure 5.25 shows the average power against the offered load. It can be clearly understood from the Figure 5.25 that both the algorithms are utilizing total traffic power in each slot.

As the delay threshold increases the power utilization also increases at the load of 30 users. As the delay threshold increases more packets are served therefore it requires more power.

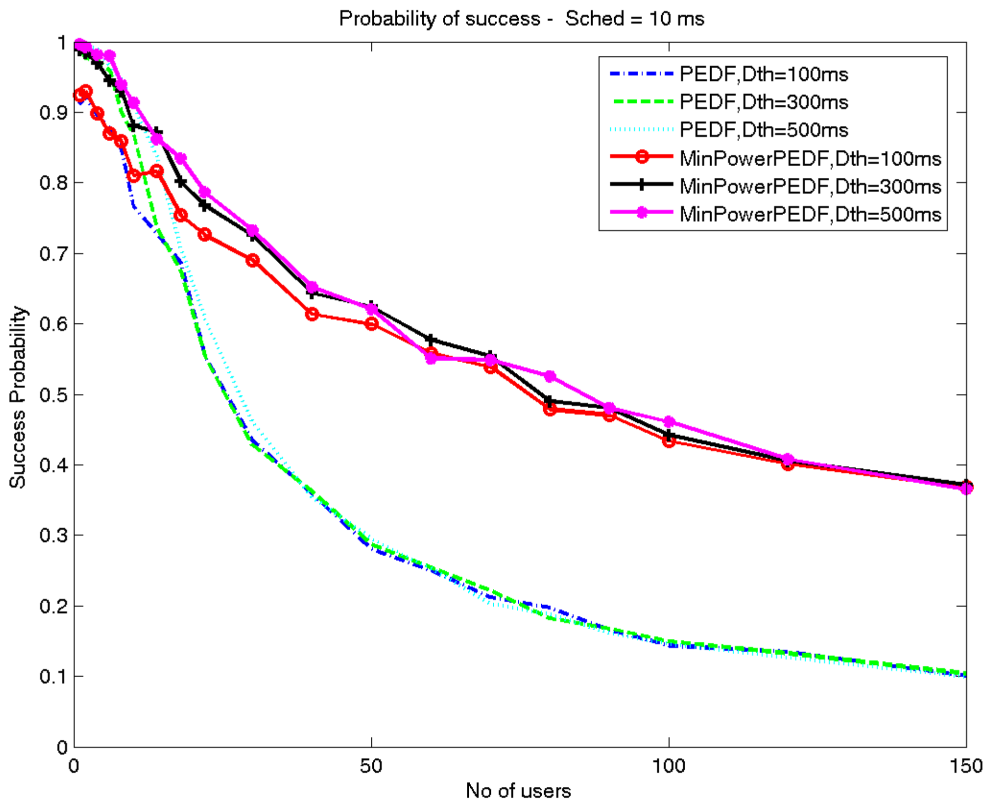

Figure 5.26: MinPower PEDF Success Probability vs. Offered load for sched=10ms

Figure 5.26 demonstrates the success probability against offered load for a scheduling interval of 10ms with delay thresholds of 100ms, 300ms and 500ms. As shown in Figure 5.26 the success rate is increased unlike PEDF algorithm where packets are served according to their deadlines. In MinPower PEDF, the packets are served according to minimum power packet thus accommodating more packets i.e. around 40% for 120 users than PEDF, which serves merely 15%. Thus, the success rate per slot is more than the PEDF as we can see from the Figure 5.26 above.

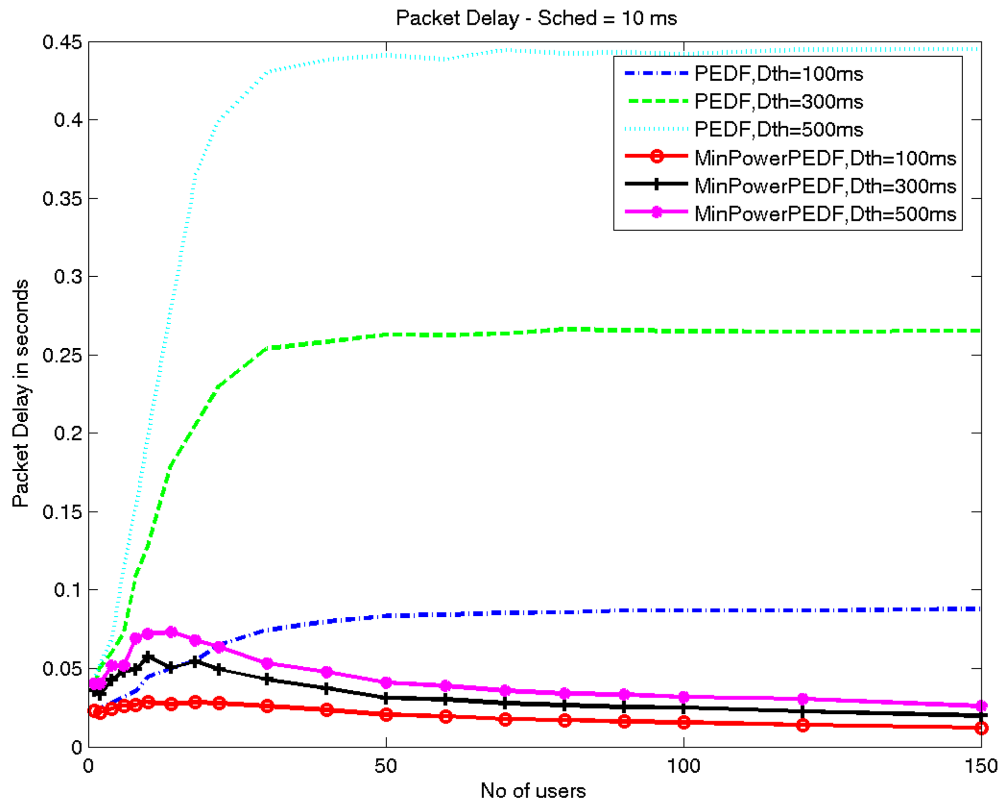

Figure 5.27: MinPower PEDF Packet Delay vs. Offered load for sched=10ms

Figure 5.27 shows the packet delay vs. offered load for a scheduling interval of 10ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MinPower PEDF algorithm are 82.9% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm the packets are served according to their arrival times.

Table 5.5 summarizes the percentage comparison of throughput, average power and success probability between MinPower PEDF and PEDF at SI=10ms for the load of 50 users.

Table 5.5: Comparison of PEDF vs. MinPower PEDF at SI=10ms for 50 users

PEDF vs. MinPower PEDF (SI=10ms for 50 users)							
	Throughput (kbps)			Average Power (watts)	Success Probability		
Dth(ms)	PEDF	MinPower PEDF	%	Total slot power is utilized in both algorithms	PEDF	MinPower PEDF	%
100	580	750	29.3▲		0.28	0.6	114.2▲
300	595	800	34.4▲		0.29	0.63	117.2▲
500	596	800	34.2▲		0.27	0.64	137 ▲

5.3.3 Comparison results of PEDF vs. MinPower PEDF for Scheduling Interval=20ms

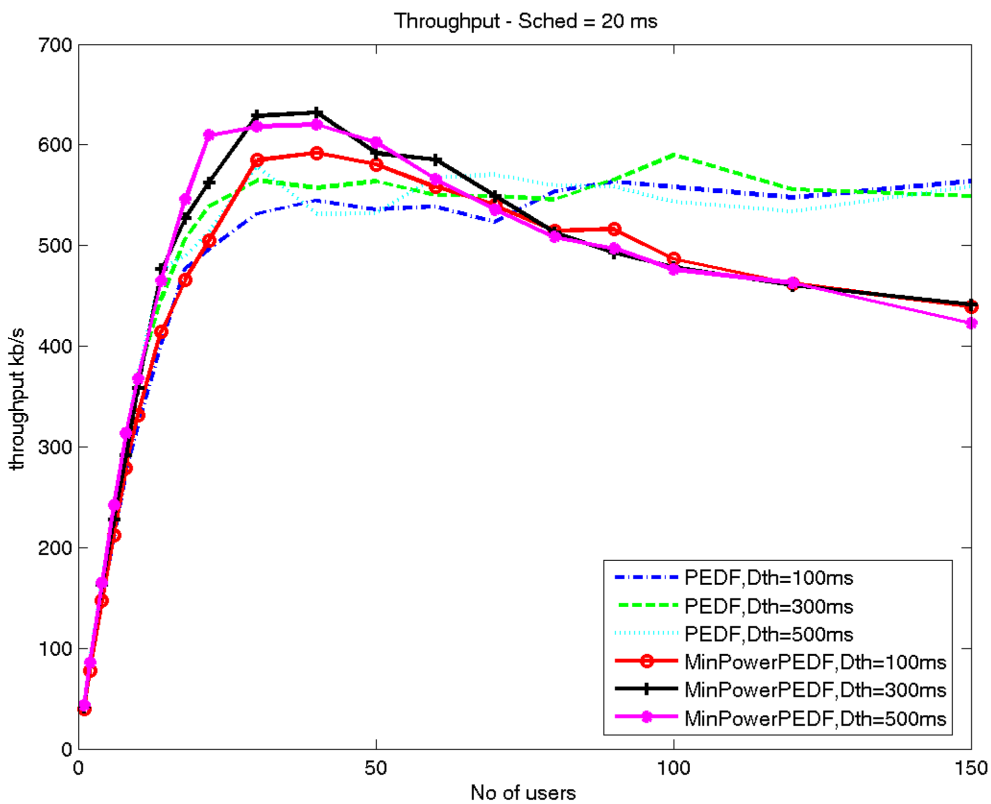

Figure 5.28: MinPower PEDF Throughput vs. Offered load for sched=20ms

Figure 5.28 demonstrates the throughput against offered load for scheduling interval 20ms with delay thresholds of 100ms, 300ms and 500ms. The throughput curve of

MinPower PEDF algorithm is initially same as the throughput of PEDF algorithm for scheduling interval 20ms. The throughput then starts decreasing as the offered load increases. The throughput increases and stabilizes as offered load increases in PEDF algorithm. For example, the throughput achieved for 150 users in MinPower PEDF algorithm is around 450kb/s whereas the throughput achieved for PEDF algorithm is around 550kb/s.

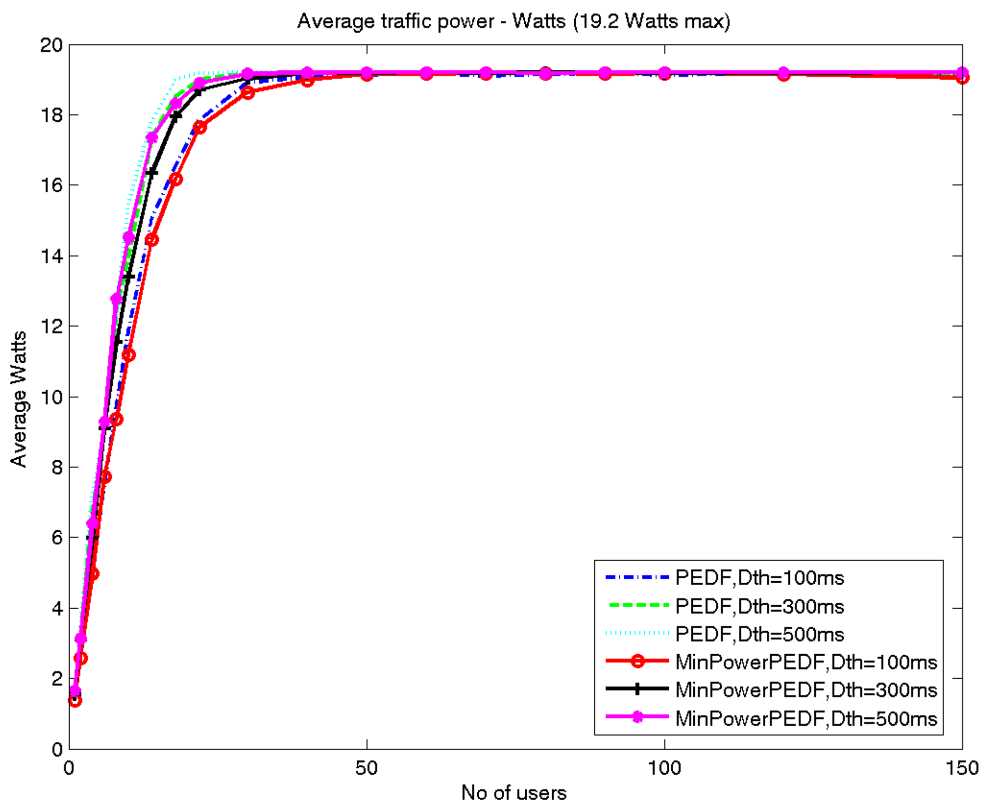

Figure 5.29: MinPower PEDF Average Power vs. Offered load for sched=20ms

Figure 5.29 demonstrates the average traffic power against offered load for a scheduling interval of 20ms with delay thresholds of 100ms, 300ms and 500ms. It can be observed that average power increases and stabilizes at the maximum traffic power. This is because total slot power is utilized for serving multiple packets in the slot in both the algorithms.

As the delay threshold increases the power utilization also increases at the load of 30 users. As the delay threshold increases more packets are served therefore require more power.

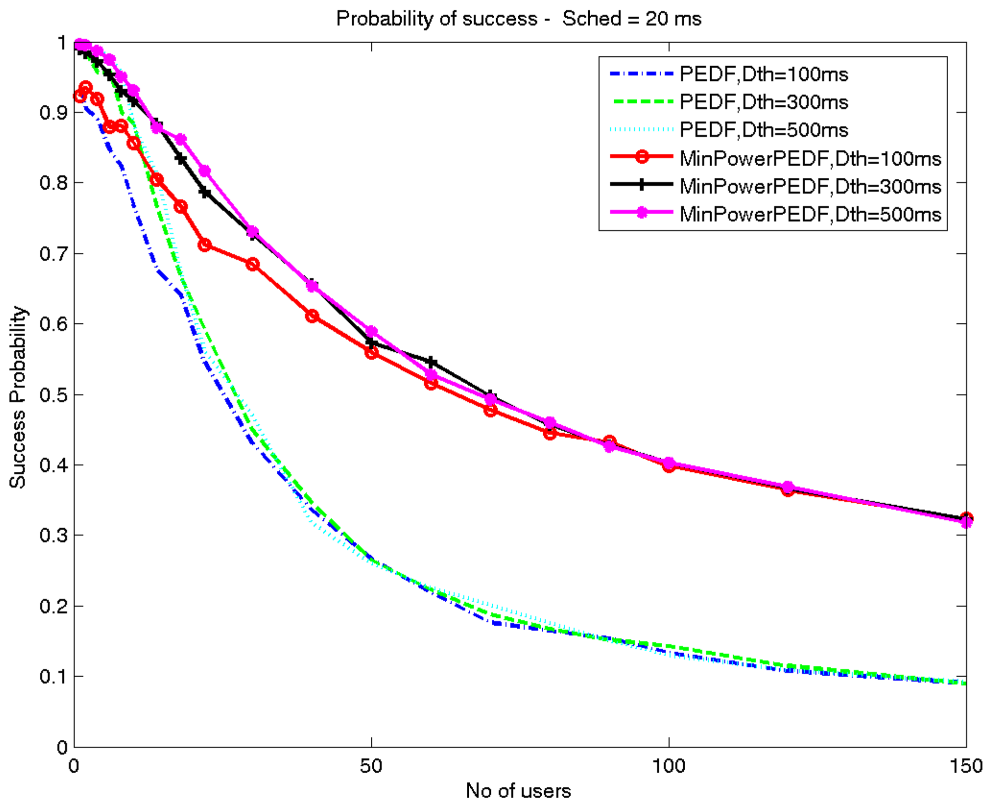

Figure 5.30: MinPower PEDF Success Probability vs. Offered load for sched=20ms

Figure 5.30 demonstrates the success probability against offered load for a scheduling interval 20ms with delay thresholds of 100ms, 300ms and 500ms. As shown in Figure 5.30 the success rate for MinPower PEDF algorithm is more than PEDF algorithm. This is because minimum packet sizes are getting served. The MinPower PEDF algorithm is able to accommodate more packets in each slot thus increasing the success rate. For example the success probability is 30% for 150 users in MinPower PEDF algorithm when compared to PEDF algorithm, which has success probability of 10% for same offered load.

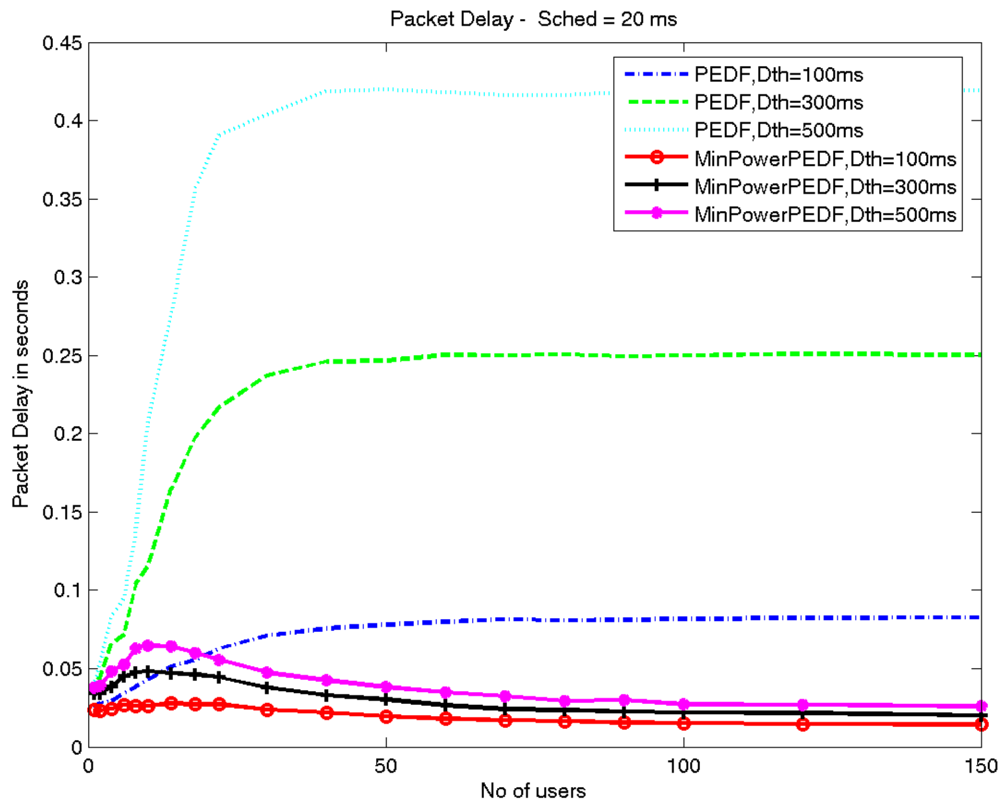

Figure 5.31: MinPower PEDF Packet Delay vs. Offered load for sched=20ms

Figure 5.31 shows the packet delay vs. offered load for a scheduling interval 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MinPower PEDF algorithm are 85.7% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm, the packets are served according to their arrival times.

Table 5.6 summarizes the percentage comparison of throughput, average power and success probability between MinPower PEDF and PEDF at SI=20ms for the load of 50 users.

Table 5.6: Comparison of PEDF vs. MinPower PEDF at SI=20ms for 50 users

PEDF vs. MinPower PEDF (SI=20ms for 50 users)							
	Throughput (kbps)			Average Power (watts)	Success Probability		
Dth(ms)	PEDF	MinPower PEDF	%	Total slot power is utilized in both algorithms	PEDF	MinPower PEDF	%
100	530	580	9.43▲		0.27	0.56	107.4▲
300	550	590	7.27▲		0.26	0.57	119.2▲
500	510	600	17.6▲		0.26	0.59	126.9▲

5.4 Effect of Scheduling Interval on MinPower PEDF

The throughput for scheduling interval 20ms stabilizes at 970kb/s. The throughput decreases to 780kb/s for 10ms scheduling interval and further decreases to 550kb/s for 5ms slot duration for the load of 80 users. This is because the throughput is inversely proportional to the scheduling interval. The average power remains constant for all scheduling interval as total traffic power is utilized to serve the multiple packets per slot until total traffic is utilized. The success rate is very good for the scheduling intervals 5ms, 10ms and 20ms.

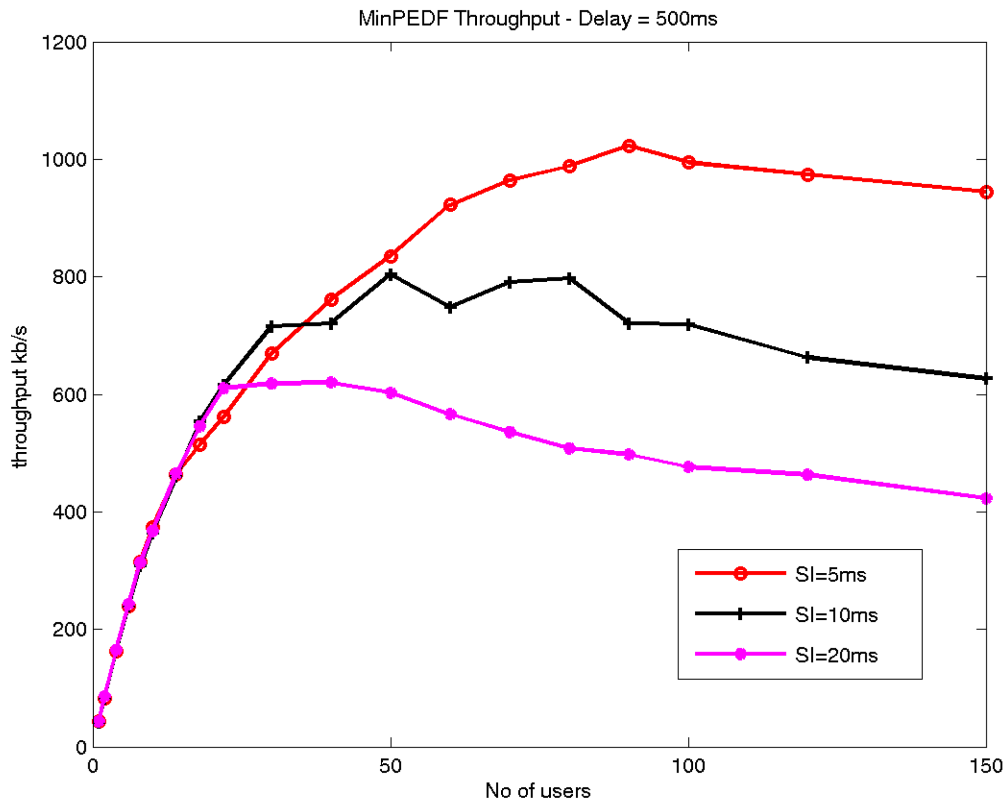

Figure 5.32: MinPower PEDF Throughput vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 5.32 shows the throughput vs. offered load for different scheduling intervals and a particular delay threshold of 500ms.The above Figure 5.32 shows that as scheduling Interval increases the throughput decreases since throughput is inversely proportional to the scheduling interval. Thus, the results of throughput when scheduling interval is 5ms is around 1000kbps for 100 users i.e. the bit rate is good for more number of users but when the scheduling interval increases to 10ms and 20ms it decreases gradually around 700kbps and 500kbps respectively i.e. bit rate decreases from for more offered load. This shows that slot duration plays an important role in supporting good bit rate for the offered load. As SI increases the bit rate decreases and thus the power decreases, but the total power consumed during the slot is not changed as SI varies as shown in Figure 5.32.

The reason for decreasing the throughput is as slot duration increases number of arrivals are increasing thus the chance of selecting minimum power packet increases as scheduling interval increases which may have smaller packet size and then smaller bit rate.

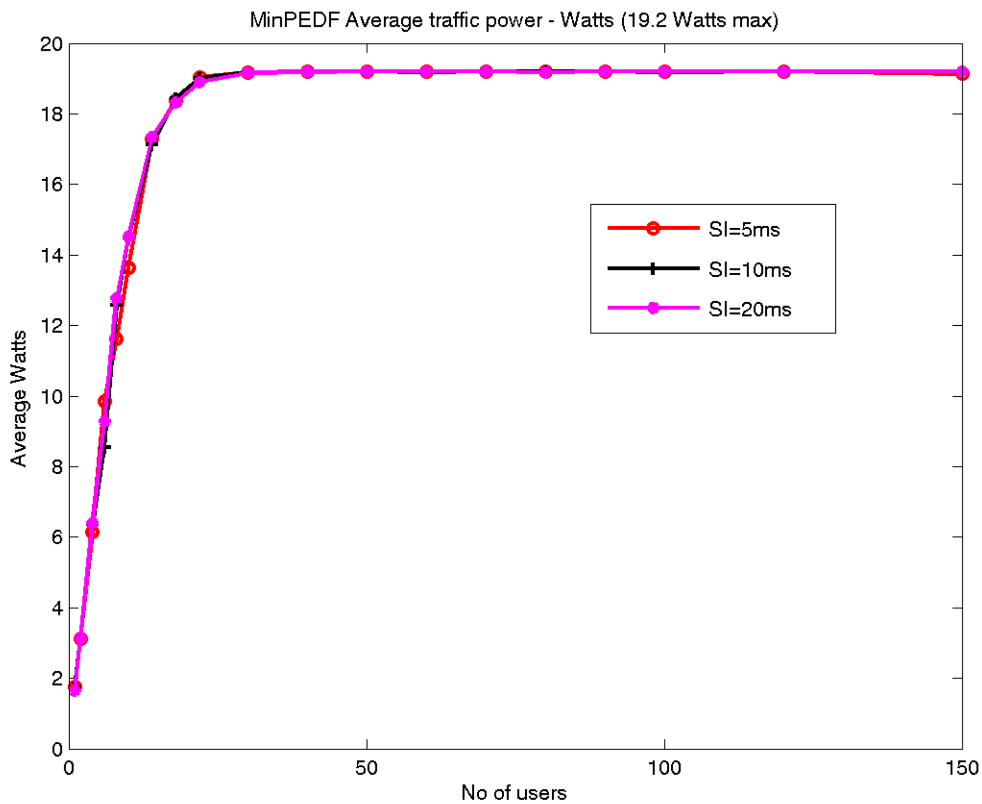

Figure 5.33: MinPower PEDF Average Power vs. Offered load for SI = 5, 10, 20ms and D_{th}=500ms

Figure 5.33 shows the average power vs. offered load for different scheduling interval and a particular delay threshold of 500ms. The power utilization is almost same for all scheduling intervals ranging from 5ms to 20ms. Thus total slot power is utilized.

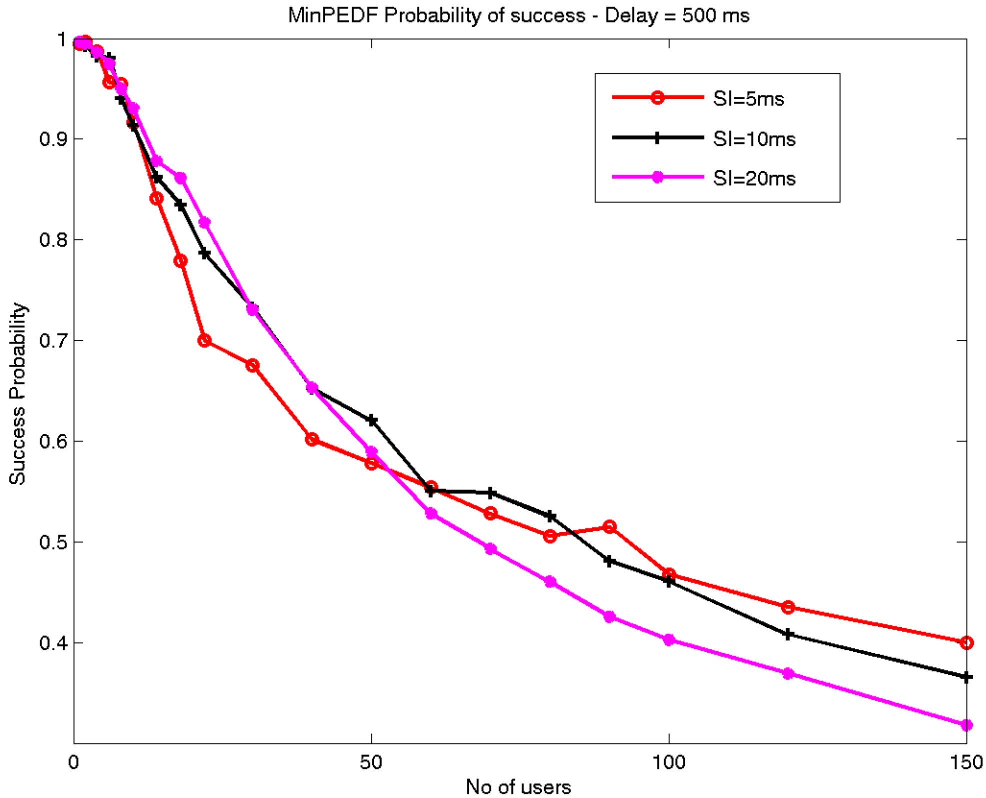

Figure 5.34: MinPower PEDF Success Prob. vs. Offered load for SI = 5, 10, 20 ms and Dth=500ms

Figure 5.34 shows the success probability vs. offered load for different scheduling interval at a particular delay threshold of 500ms.The success rate for the scheduling interval 5ms is very high (45% for 120 users) thus serving more number of users in the system. It can be observed from the Figure 5.34 that as the Scheduling interval increases from 10ms to 20ms, then the success rate gradually decreases from 42% to 35% respectively for 120 users. The arrivals happening in the 5ms-scheduling interval is less so they are being served faster due to less packet delays, thus serving more packets. On the other hand, as the scheduling interval increases, the arrivals accumulating in that slot duration increases. This has an effect in increasing the packet delays and results into more number of packets discarded due to the restriction of delay threshold. The success probability is less for lower number of users because the packets are less to be scheduled but as the load increases the number of packets increases thus increasing the success rate.

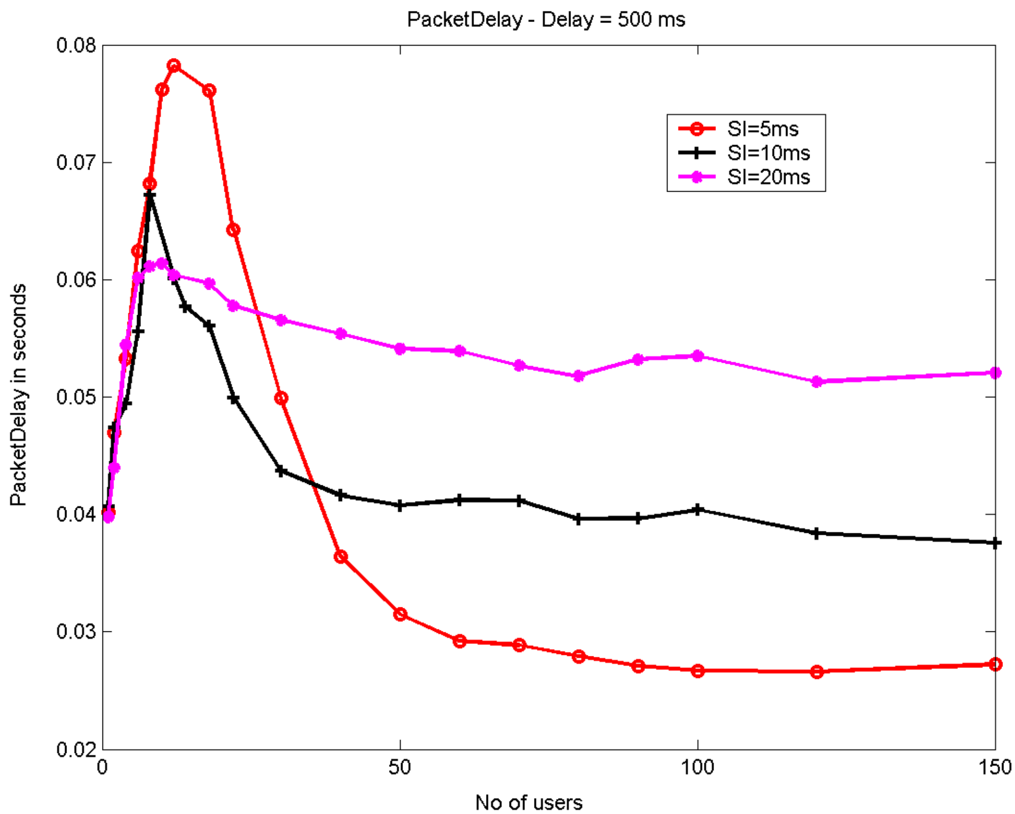

Figure 5.35: MinPower PEDF Packet Delay. Vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 5.35 shows the packet delay vs. offered load for scheduling intervals 5ms, 10ms and 20ms and for a particular delay threshold 500ms. The packet delays of MinPower PEDF algorithm decreases as scheduling interval increases from 5ms to 20ms.

Finally, Figure 5.36 shows the fairness vs. offered load for scheduling intervals 5ms, 10ms and 20ms and for a particular delay threshold 100ms. The fairness of MinPower PEDF algorithm increases as scheduling interval increases from 5ms to 20ms. The fairness of the MinPower PEDF is below 70% for 150 users for SI=20ms where as fairness for PEDF is below 60%.

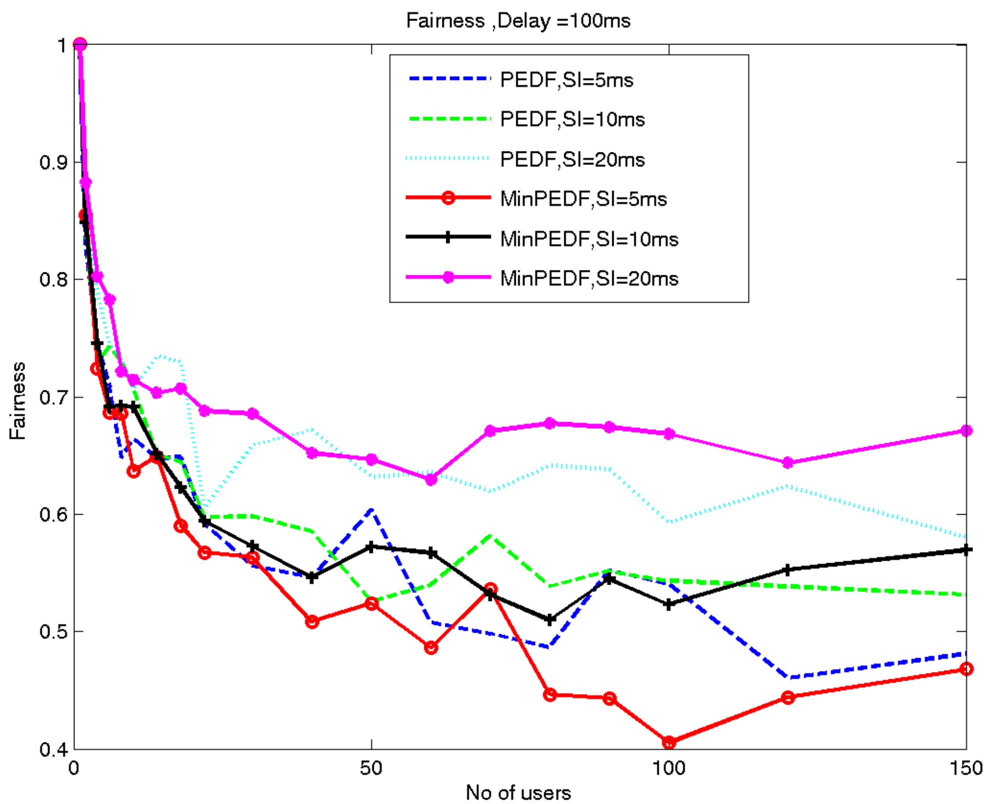

Figure 5.36: Fairness. Vs. Offered load for SI = 5, 10, 20 ms and D_{th}=100ms

In PEDF, the head-of-queue (HOQ) packet of each queue is compared to determine which comes first and is scheduled according to earliest deadline. This order is fixed, and if a connection goes into bad state it will have to wait until it comes out of bad state and the other HOQ packets are served first. The second packet in the same queue faces the same challenge. Thus making users to starve till the connection changes to good state. MinPower PEDF is better as the packets are sorted in every slot. Hence if the connection goes in a bad state, in the next slot the next user packet may get scheduled because of minimum power.

CHAPTER 6

RESULTS AND DISCUSSION OF MAXPOWER EDF AND PEDF ALGORITHMS

This chapter discusses the results of MaxPower EDF algorithm and MaxPower PEDF algorithm with their counterparts EDF and PEDF respectively. The effect of Qos parameter i.e. delay threshold dealt in depth to analyze the results. Various scenarios are simulated for each algorithm to have a deep understanding of these algorithms.

6.1 MaxPower EDF Performance under different Scheduling Intervals

6.1.1 Comparison results of EDF vs. MaxPower EDF for Scheduling Interval=5ms

This section describes the comparison of MaxPower EDF with its counterpart EDF algorithm. The variation effects of the scheduling interval and delay threshold on these algorithms are compared.

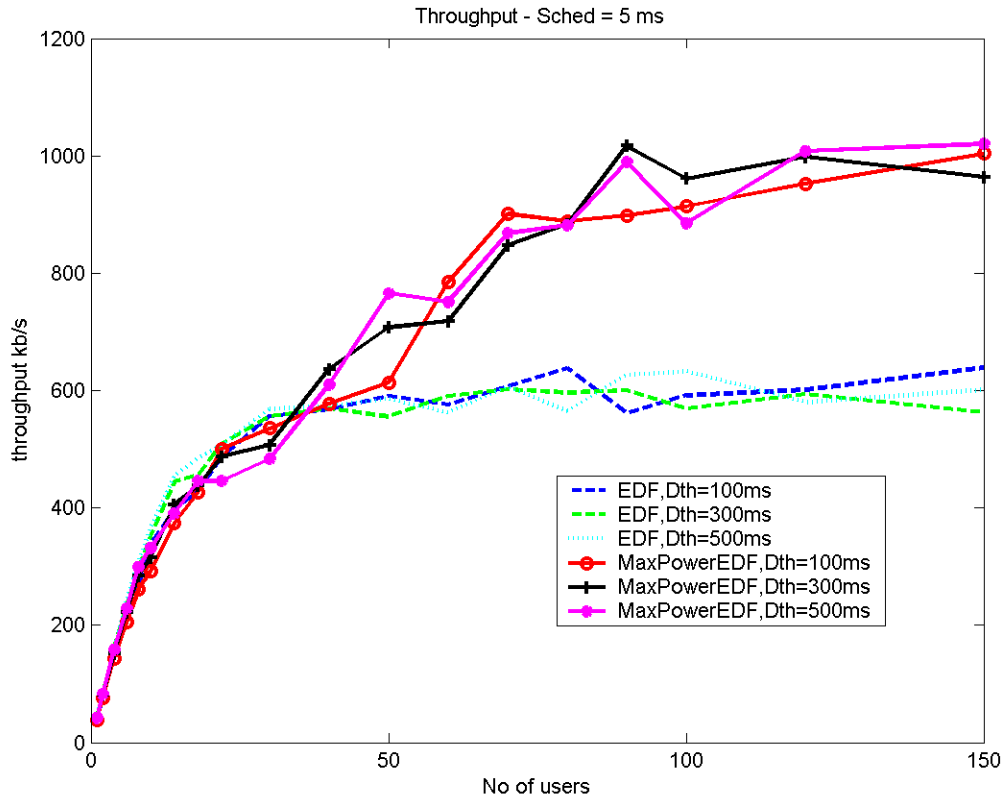

Figure 6.1: MaxPower EDF Throughput vs. Offered load for sched=5ms

Figure 6.1 demonstrates the throughput for delay thresholds 100ms, 300ms and 500ms. As the no of users increases the throughput increases. In Figure 6.1 MaxPower EDF algorithm gives priority to the maximum power packet from all the arrivals. The maximum power packet has the highest rate due to maximum size of the packet and may be farther distance from BS. This enhances the throughput since throughput depends on the packet size. On the other hand, the EDF algorithm serves the packet according to arrival time irrespective of power, thus stabilizing the throughput. For example, the throughput achieved for 150 users in MaxPower EDF algorithm is 1000 kb/s when compared to EDF algorithm, which achieves throughput of 600kb/s for the same offered load.

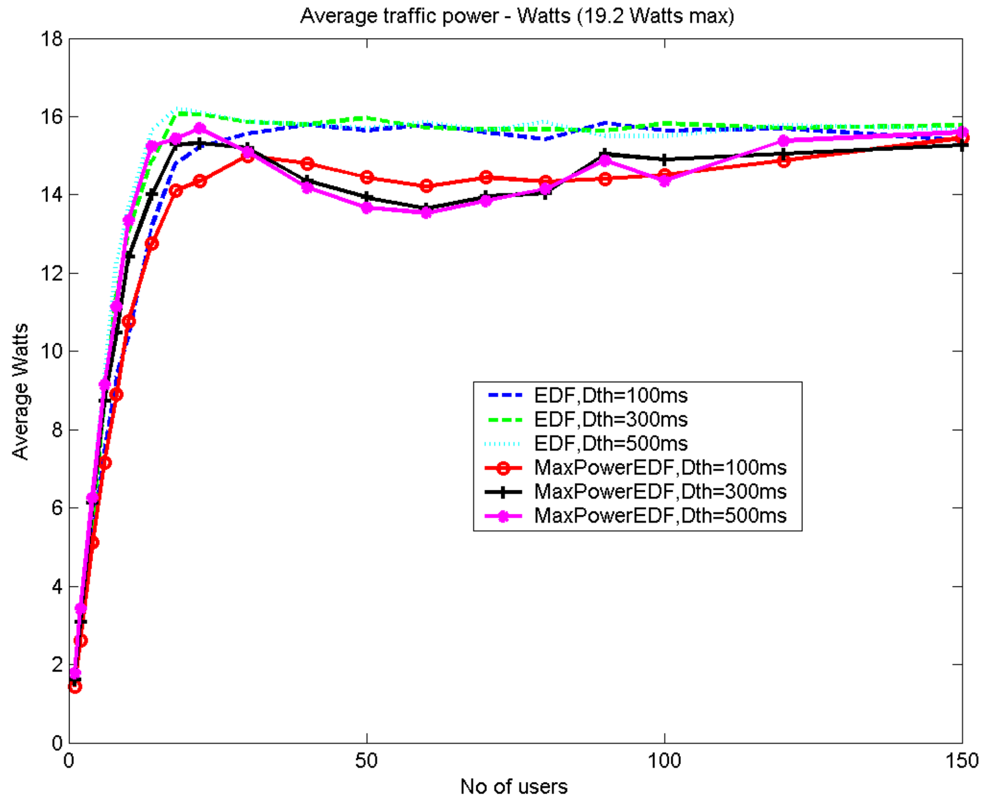

Figure 6.2: MaxPower EDF Average Power vs. Offered load for sched=5ms

Figure 6.2 depicts the average power vs. no of users for Scheduling interval 5ms and delay thresholds 100ms, 300ms and 500ms for EDF algorithm and EDF algorithm. The MaxPower EDF algorithm is stabilizing at the average of 14-15 watts and EDF algorithm is stabilizing for little more at 16 watts.

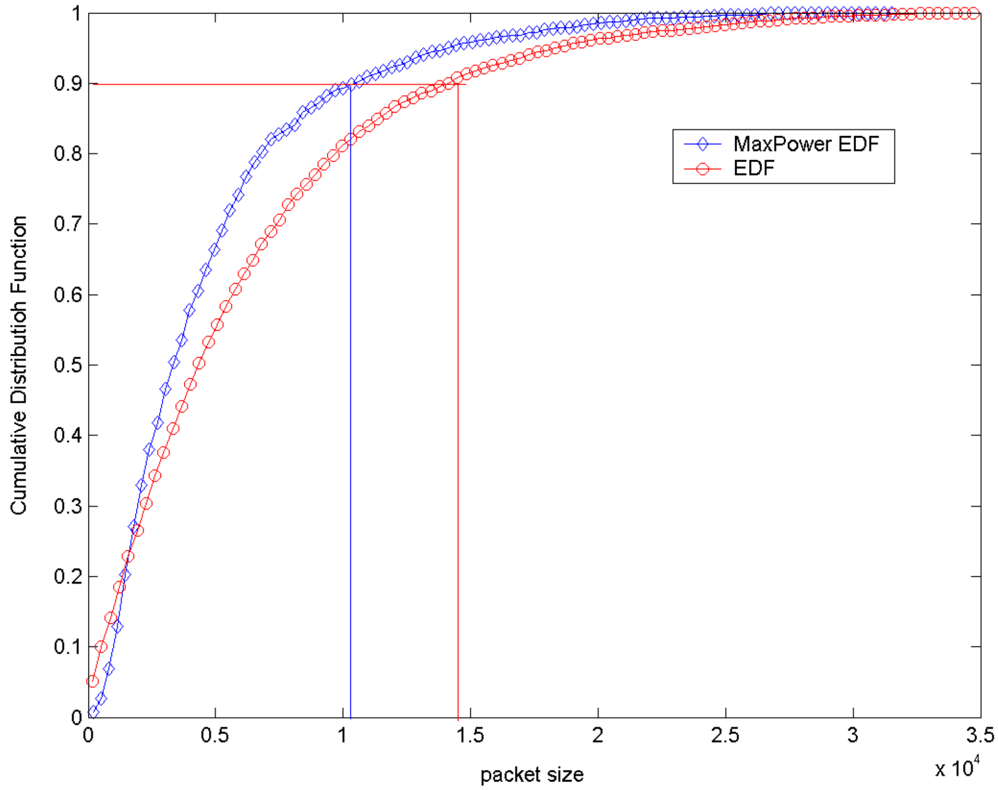

Figure 6.3: MaxPower EDF Success CDF vs. packet size

Figure 6.3 demonstrates the CDF for EDF algorithm vs. MaxPower EDF algorithm for 100users. It is clear from the Figure 6.3 that 90% of the time, EDF is serving packet of size less than 14000 bits whereas MaxPower EDF is serving packets of size less than 11000bits.The MaxPower EDF is serving smaller packets due to partial serving of the packets.

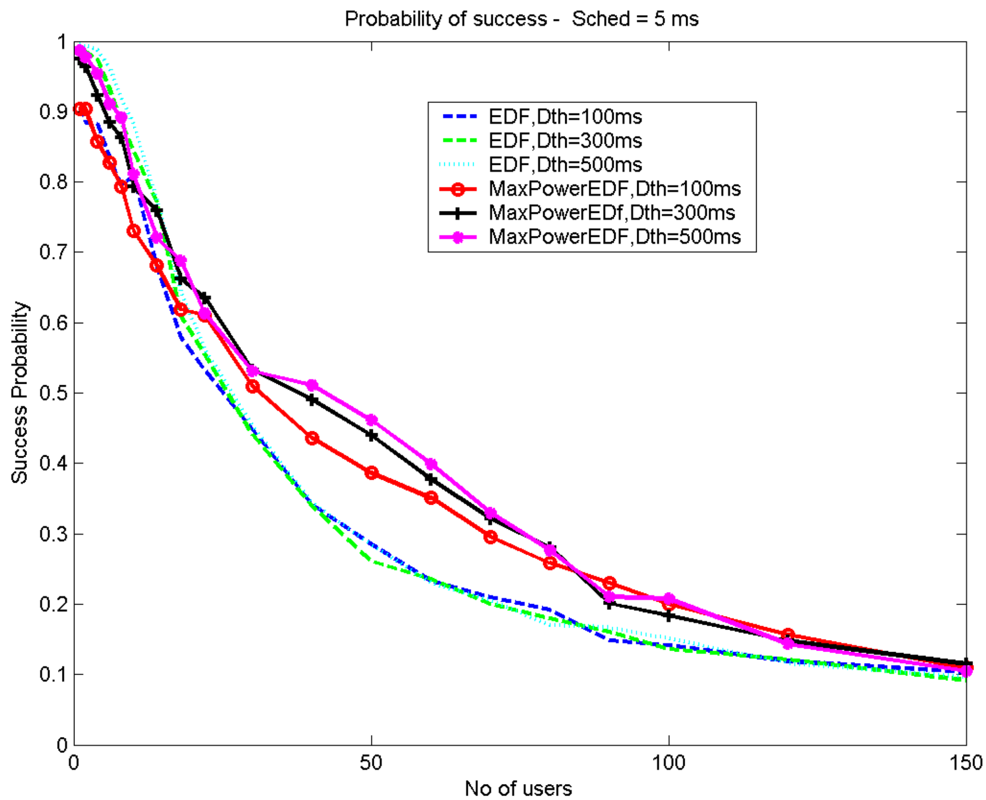

Figure 6.4: MaxPower EDF Success Probability vs. Offered load for sched=5ms

Figure 6.4 demonstrates the comparison of EDF algorithm and Max Power EDF algorithm for the delay thresholds 100ms, 300ms and 500ms. Figure 6.4 plotted for slot duration of 5ms.The success probability is around 30 % for MaxPower EDF where as it is around 25% for EDF.

The success rate for MaxPower EDF is better than its counterpart EDF algorithm. As the users increases the success rate becomes equal to the success rate of EDF algorithm. The success rate is decreasing as users increases. The reason is that the packet size used for serving the maximum power packet is large and thus served partially and the same packet with remaining bits is served as the next packet. Thus, it takes two slots or even more to serve one full packet.

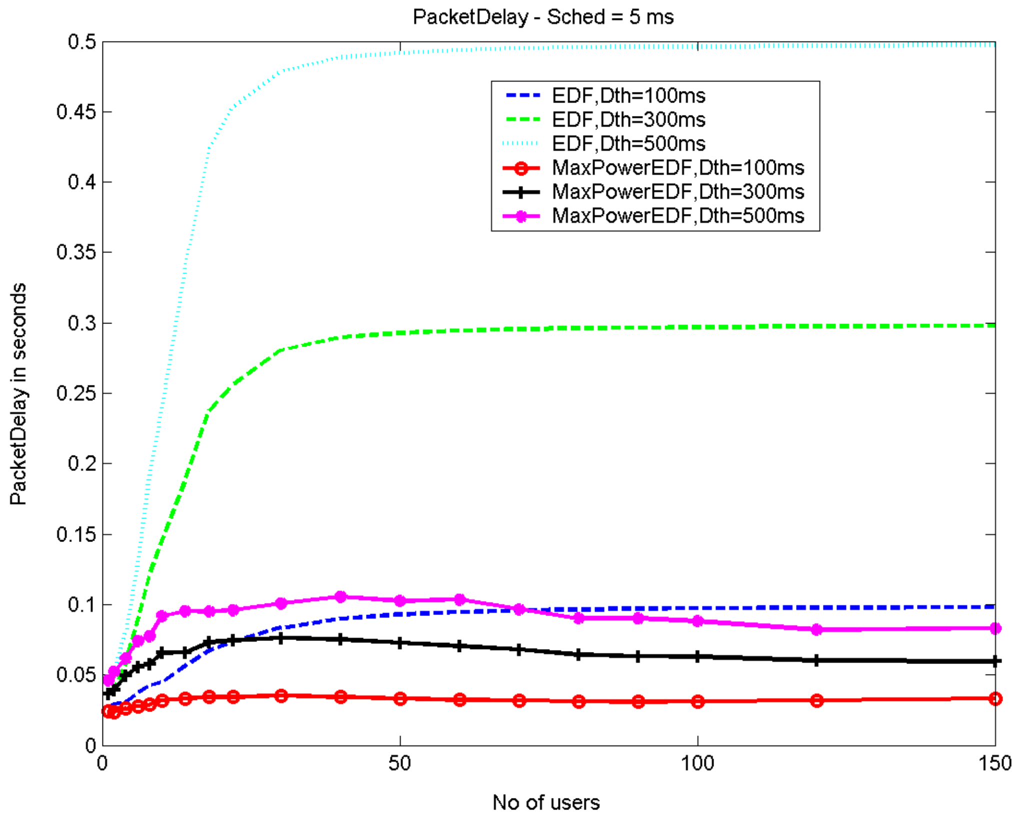

Figure 6.5 : MaxPower EDF Packet Delay vs. Offered load for sched=5ms

Figure 6.5 shows the packet delay vs. offered load for a scheduling interval 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower EDF algorithm are 79.16% less than EDF algorithm because fresh packets are being served in that slot. In EDF algorithm, the packets are served according to their arrival times.

Table 6.1 summarizes the percentage comparison of throughput, average power and success probability between MaxPower EDF and EDF at SI=5ms for the load of 50 users.

Table 6.1: Comparison of EDF vs. MaxPower EDF at SI=5ms for 50 users

EDF vs. MaxPower EDF (SI=5ms for 50 users)										
	Throughput (kbps)			Average Power (watts)			Success Probability			
Dth (ms)	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%
100	580	610	5.17▲	15.7	14.5	7.6▼	0.28	0.38	35.7▲
300	550	700	27.2▲	15.6	14	10.2▼	0.27	0.45	66.6▲
500	570	780	36.8▲	15.5	13.8	10.9▼	0.27	0.47	74▲

6.1.2 Comparison results of EDF vs. MaxPower EDF for Scheduling Interval=10ms

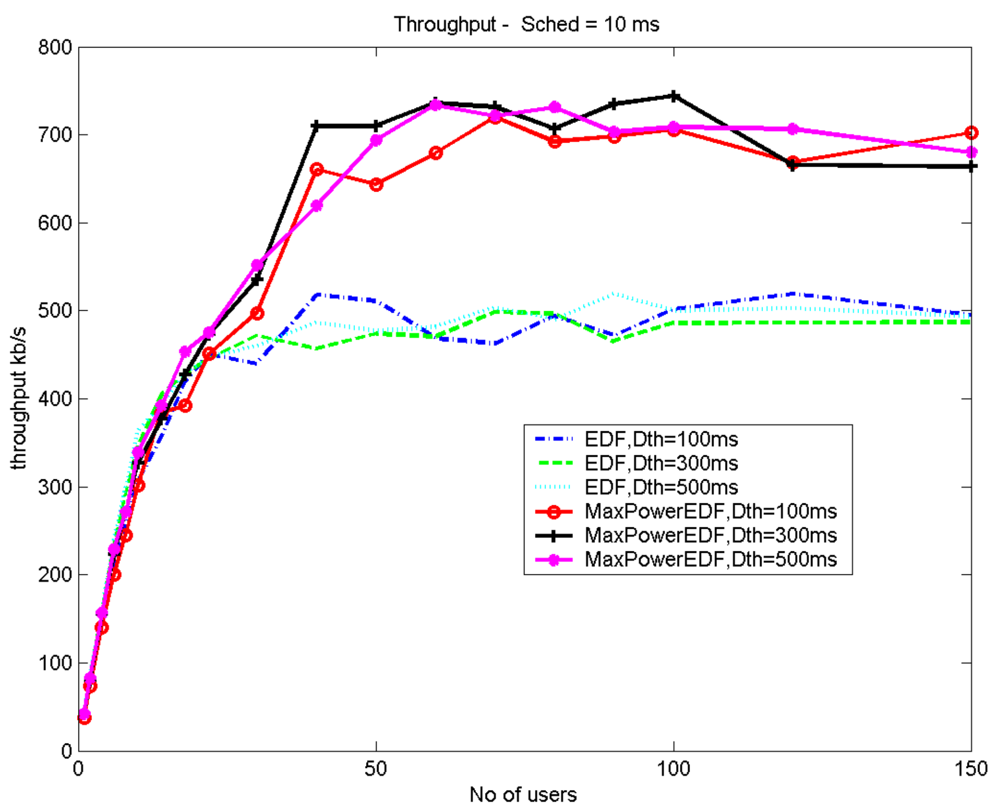

Figure 6.6: MaxPower EDF Throughput vs. Offered load for sched=10ms

Figure 6.6 depicts the throughput vs. offered load for the delay thresholds 100ms, 300ms and 500ms for a scheduling interval of 10 ms. the throughput increases as the offered load increases as the packet size used to serve the maximum power packet is large so the bit rate is more. Thus, the throughput increases for MaxPower EDF algorithm as against the EDF algorithm. For example, the throughput achieved for 150 users in maximum power EDF algorithm is 700kb/s when compared to EDF algorithm that achieves the maximum throughput of 500kb/s for the same offered load.

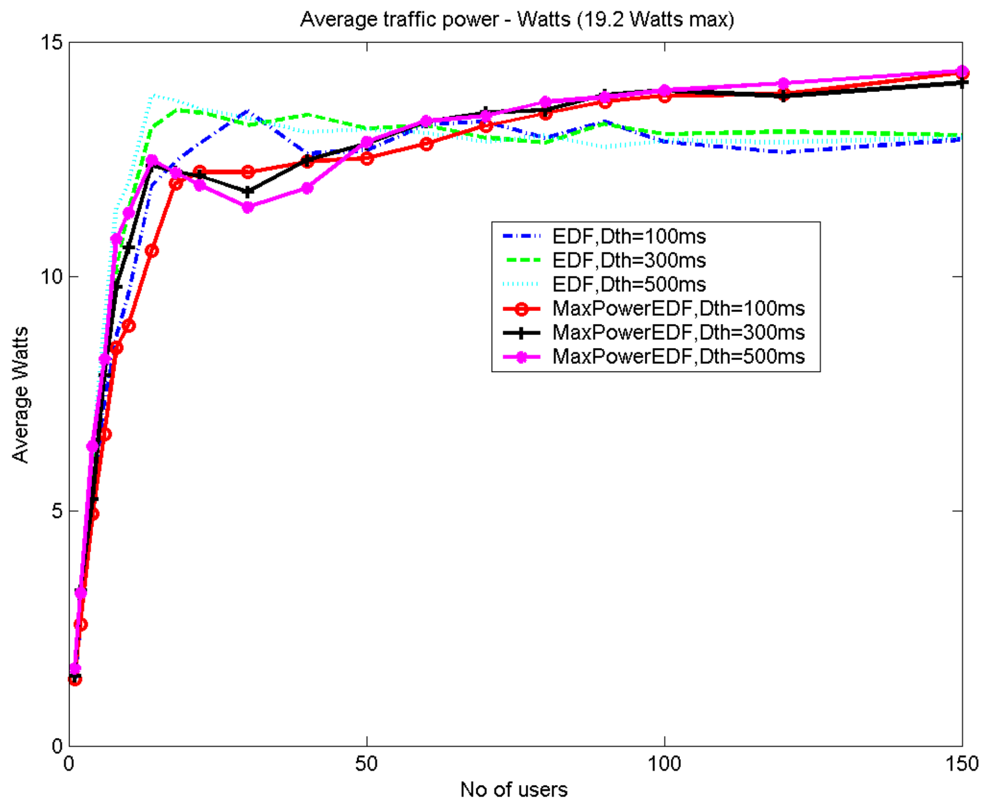

Figure 6.7: MaxPower EDF Average Power vs. Offered load for sched=10ms

Figure 6.7 depicts the average power vs. offered load for the scheduling interval of 10ms and delay thresholds 100ms, 300ms and 500 ms.

The average power of MaxPower EDF algorithm starts increasing as the number of arrivals increased due to the increase of slot duration from 5ms to 10ms. This algorithm selects the maximum power packet and serves accordingly thus increasing the slot power. The EDF algorithm selects the packet according to earliest deadline irrespective of the power. For example, the average power utilized for 150 users in MaxPower EDF algorithm is approximately 14 watts when compared to EDF algorithm that utilizes approximately 13 watts for the same offered load.

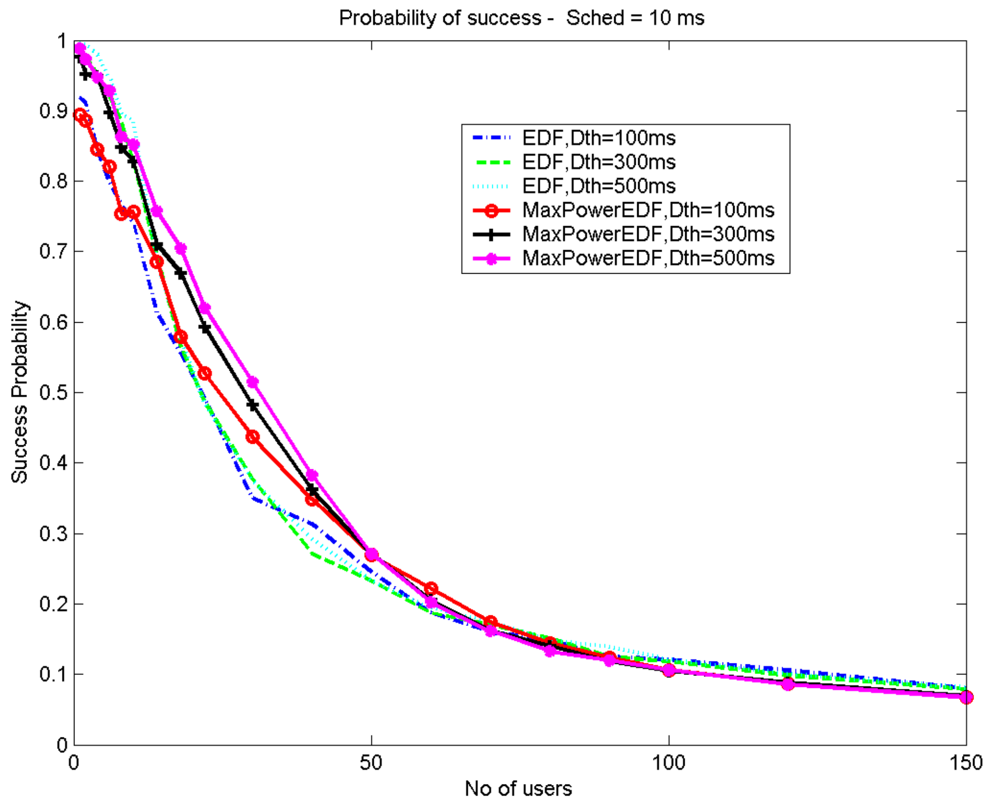

Figure 6.8: MaxPower EDF Success Probability vs. Offered load for sched=10ms

Figure 6.8 demonstrates the success probability vs. offered load for a scheduling interval of 10ms and delay thresholds 100ms, 300ms and 500ms.The success rate decreases as the offered load increases in MaxPower EDF algorithm. This is because as the scheduling interval increases the number of arrivals happening also increases. The maximum power packet is selected among the arrivals. Due to the maximum power of the packet, the packet is served partially. The remaining bits are served in the next slot thus decreasing the success rate. Furthermore, more number of smaller packets will be dropped because of reaching their maximum delay thresholds. The success rate is almost the same for both the algorithms.

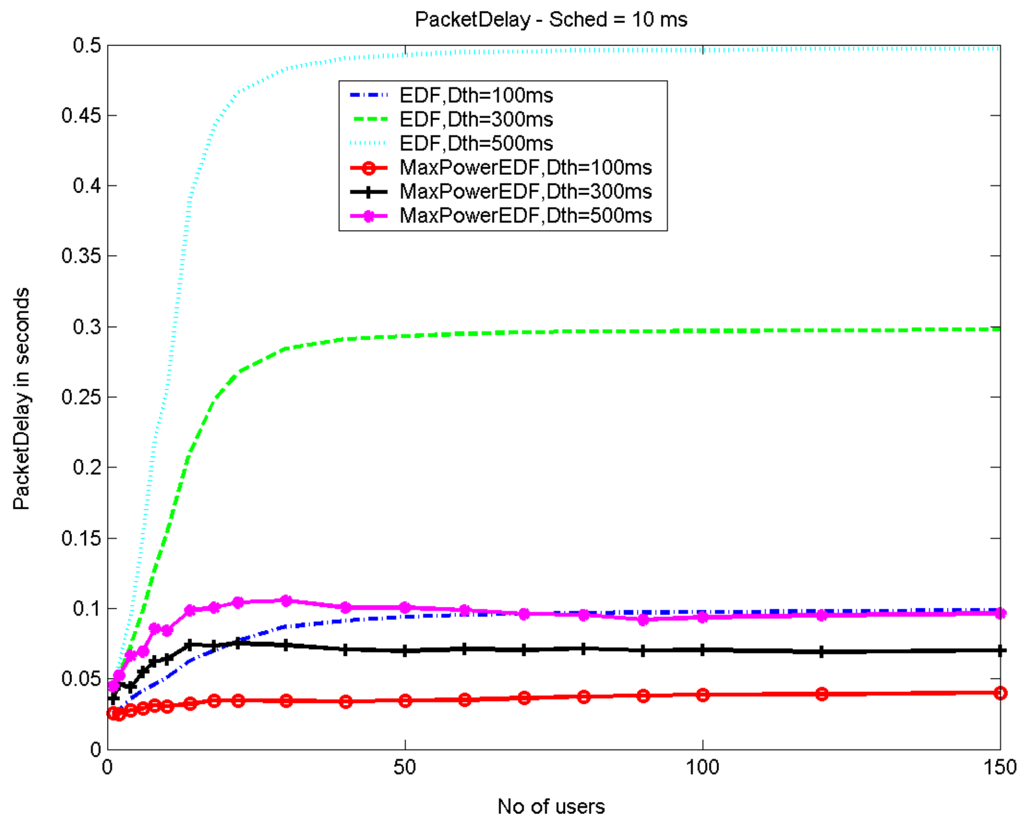

Figure 6.9 : MaxPower EDF Packet Delay vs. Offered load for sched=10ms

Figure 6.9 shows the packet delay vs. offered load for a scheduling interval 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower EDF algorithm are 79.6% less than EDF algorithm because new arrived packets are being served in the slot. In EDF algorithm, the packets are served according to their arrival times.

Table 6.2 summarizes the percentage comparison of throughput, average power and success probability between MaxPower EDF and EDF at SI=10ms for the load of 50 users.

Table 6.2: Comparison of EDF vs. MaxPower EDF at SI=10ms for 50 users

EDF vs. MaxPower EDF (SI=10ms for 50 users)									
	Throughput (kbps)			Average Power (watts)			Success Probability		
Dth (ms)	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%
100	500	650	30▲	12.5	12.3	1.6▼	0.25	0.26	4▲
300	483	680	40.7▲	12.8	12.4	3.1▼	0.24	0.26	8.33▲
500	480	700	45.8▲	12.8	12.5	2.3▼	0.23	0.26	13.04▲

6.1.3 Comparison results of EDF vs. MaxPower EDF for Scheduling Interval=20ms

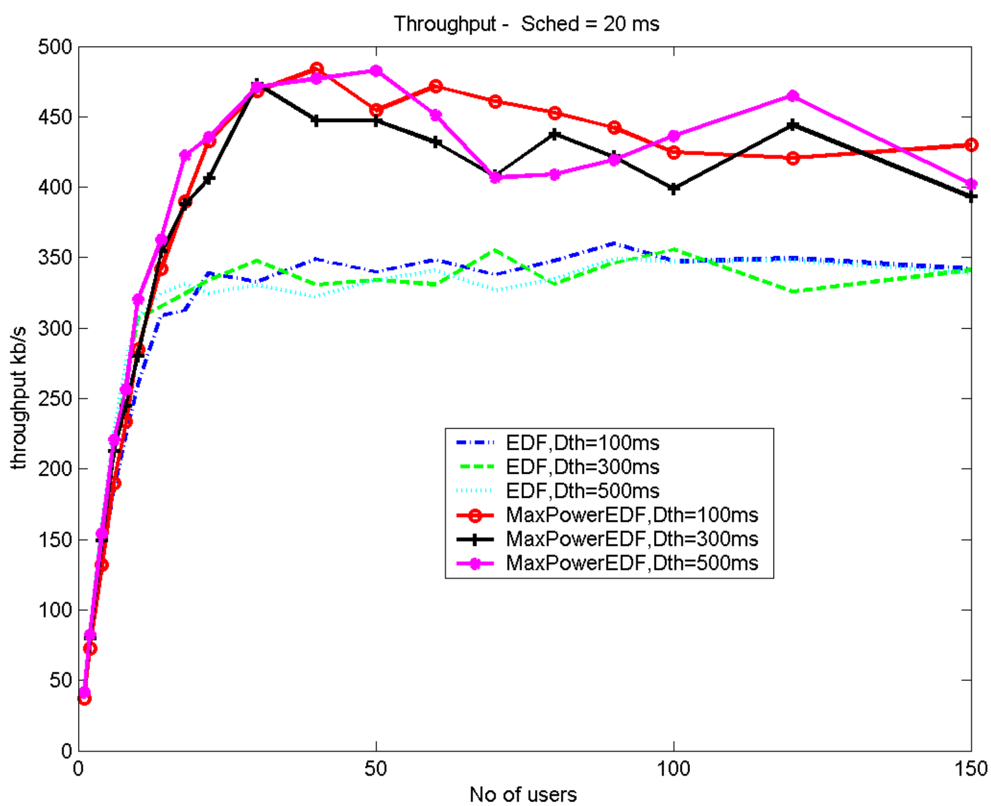

Figure 6.10: MaxPower EDF Throughput vs. Offered load for sched=20ms

Figure 6.10 depict the throughput vs. offered load for the scheduling interval of 20ms and delay thresholds 100ms, 300ms and 500 ms. In MaxPower EDF algorithm, the throughput increases as the offered load increases. In this algorithm, the maximum power packet is selected among the arrivals happening in that slot. This maximum power packet has the highest rate due to the large packet size. Thus, it clearly depicts the increase in throughput in MaxPower EDF algorithm when compared to the EDF algorithm that serves according to earliest deadline irrespective of the power. For example, the throughput achieved by 150 users in maximum power EDF algorithm is approximately 400kb/s when compared to EDF algorithm that achieves the maximum throughput of 350kb/s.

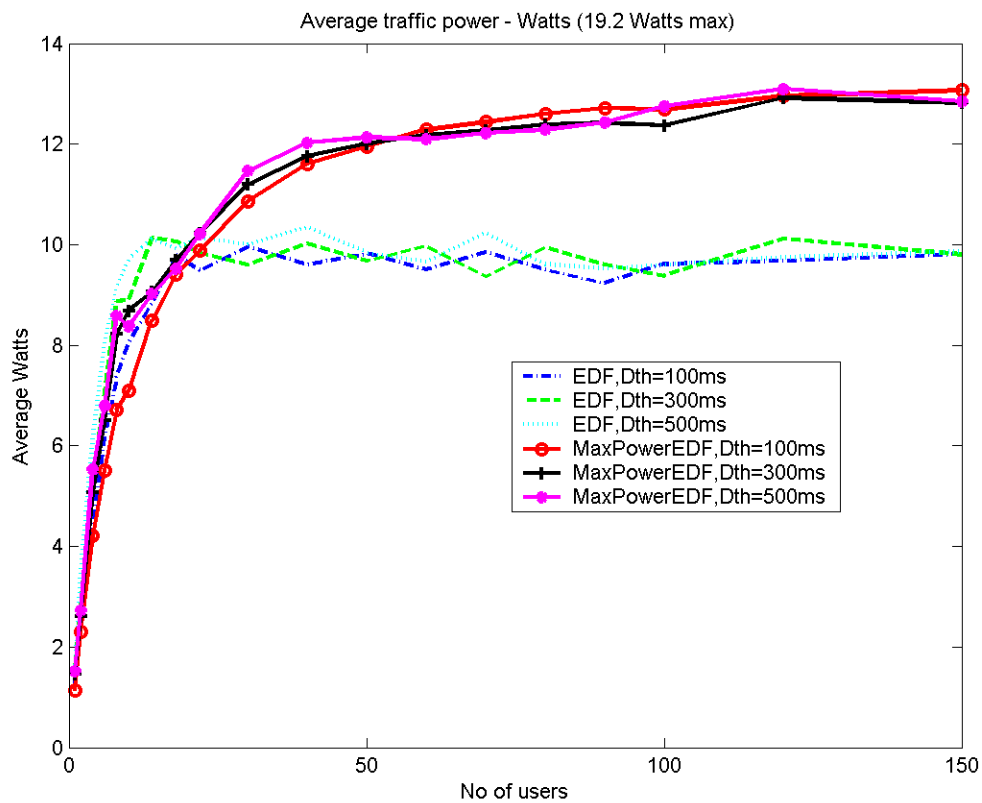

Figure 6.11: MaxPower EDF Average Power vs. Offered load for sched=20ms

Figure 6.11 demonstrates the average power vs. offered load. As the scheduling interval increases from 10 ms to 20 ms the number of arrivals, happening in the slot also increases in MaxPower EDF algorithm. The maximum power packet is selected from the packets, which have arrived. On the other hand, the EDF algorithm serves according to earliest deadline irrespective of the power of the packet. For example, the average power utilized for 150 users is 13 watts for MaxPower EDF algorithm when compared to EDF algorithm, which utilizes approximately 10 watts for the same offered load.

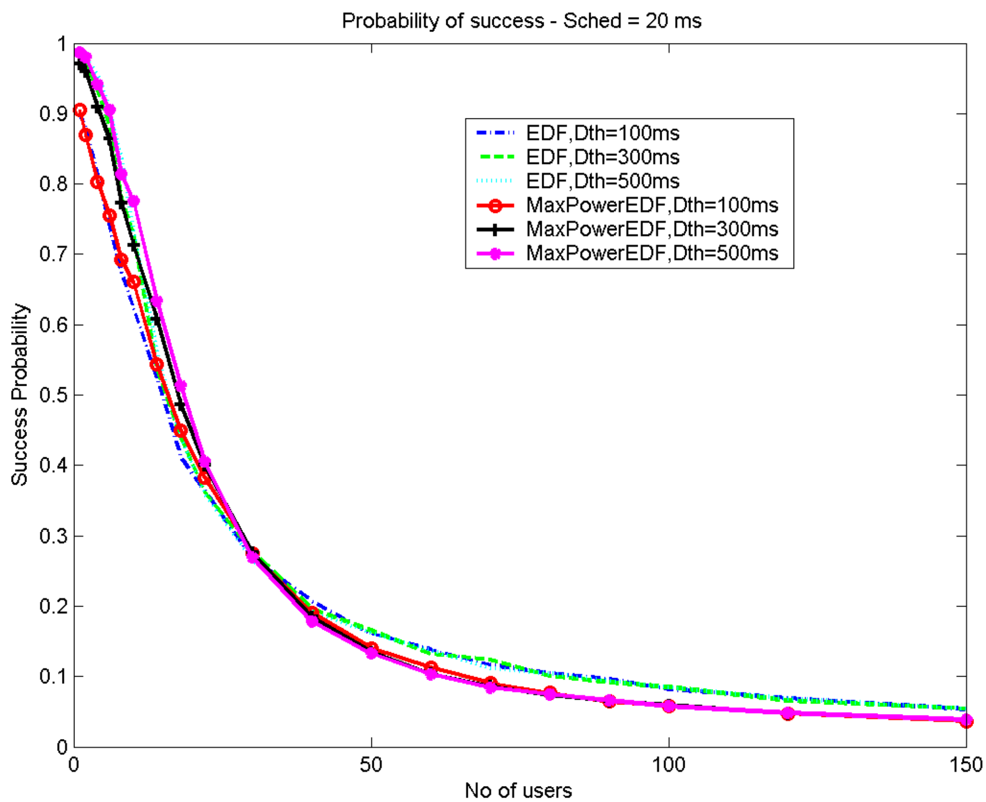

Figure 6.12: MaxPower EDF Success Probability vs. Offered load for sched=20ms

Figure 6.12 shows the success rate vs. offered load. For scheduling interval of 20ms and delay thresholds of 100ms, 300ms and 500ms the success rate drastically decreases as the offered load increases. This is due to increased in partial serving of packets in that slot duration thus decreasing the success rate.

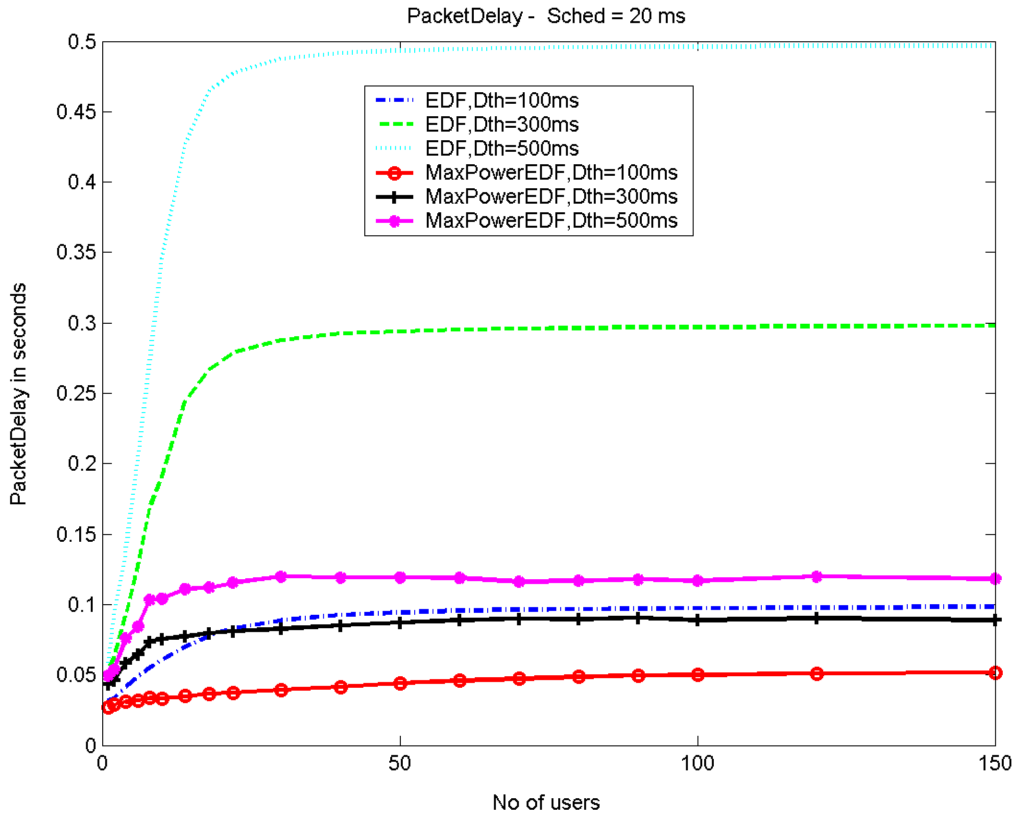

Figure 6.13: MaxPower EDF Packet Delay vs. Offered load for sched=20ms

Figure 6.13 illustrates the packet delay vs. offered load for a scheduling interval of 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower EDF algorithm are 75.5% less than EDF algorithm since newly arrived packets are being served in that slot. In EDF algorithm, the packets are served according to their arrival times.

Table 6.3 summarizes the percentage comparison of throughput, average power and success probability between MaxPower EDF and EDF at SI=20ms for the load of 50 users.

Table 6.3: Comparison of EDF vs. MaxPower EDF at SI=20ms for 50 users

EDF vs. MaxPower EDF (SI=20ms for 50 users)									
	Throughput (kbps)			Average Power (watts)			Success Probability		
Dth(ms)	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%	EDF	MaxPower EDF	%
100	340	450	32.3▲	9.8	11.6	18.3▲	0.14	0.13	7.1▼
300	336	440	30.9▲	9.7	11.7	20.6▲	0.13	0.12	7.6▼
500	335	475	41.7▲	9.6	12	25 ▲	0.12	0.115	4.1▼

6.2 Effect of Scheduling Interval on MaxPower EDF

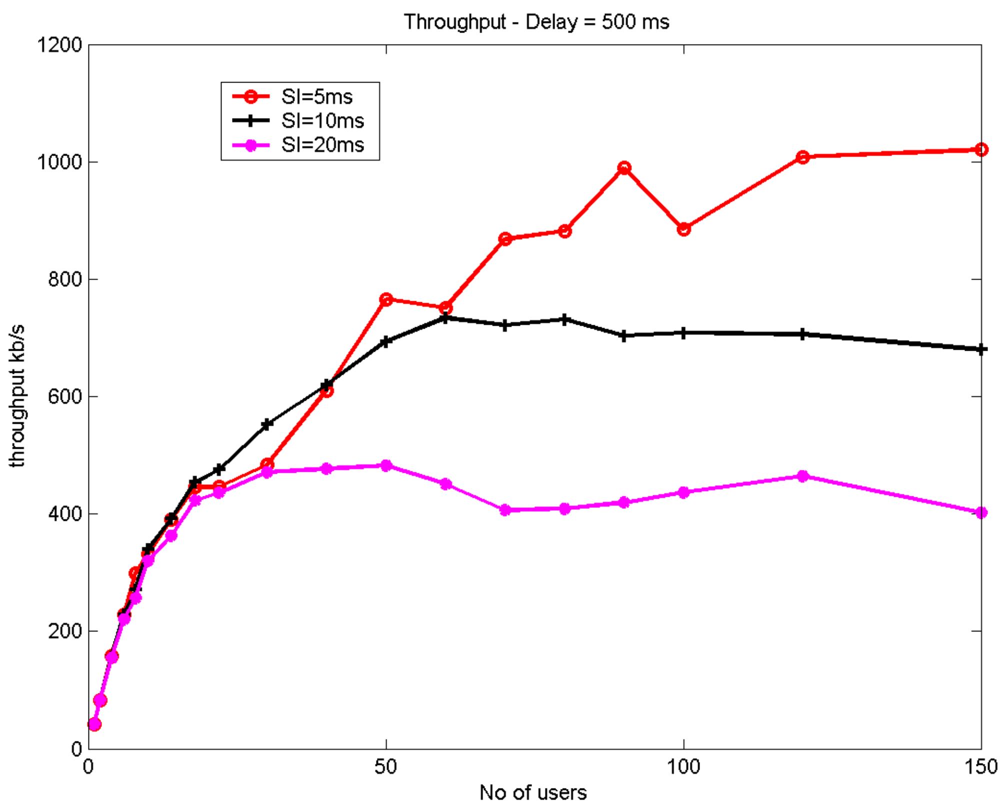

Figure 6.14 : MaxPower EDF Throughput vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 6.14 shows the throughput vs. offered load for different scheduling intervals and a particular delay threshold of 500ms.The above Figure 6.14 shows that as scheduling Interval increases the throughput decreases since throughput is inversely proportional to the scheduling interval. Thus, the results of throughput when scheduling interval is 5ms is very high i.e., the bit rate is favorable for more number of users but when the scheduling interval increases to 10ms and 20ms it decreases gradually i.e. bit rate decreases for more offered load. This shows that the slot duration plays an important role in supporting good bit rate for the offered load.

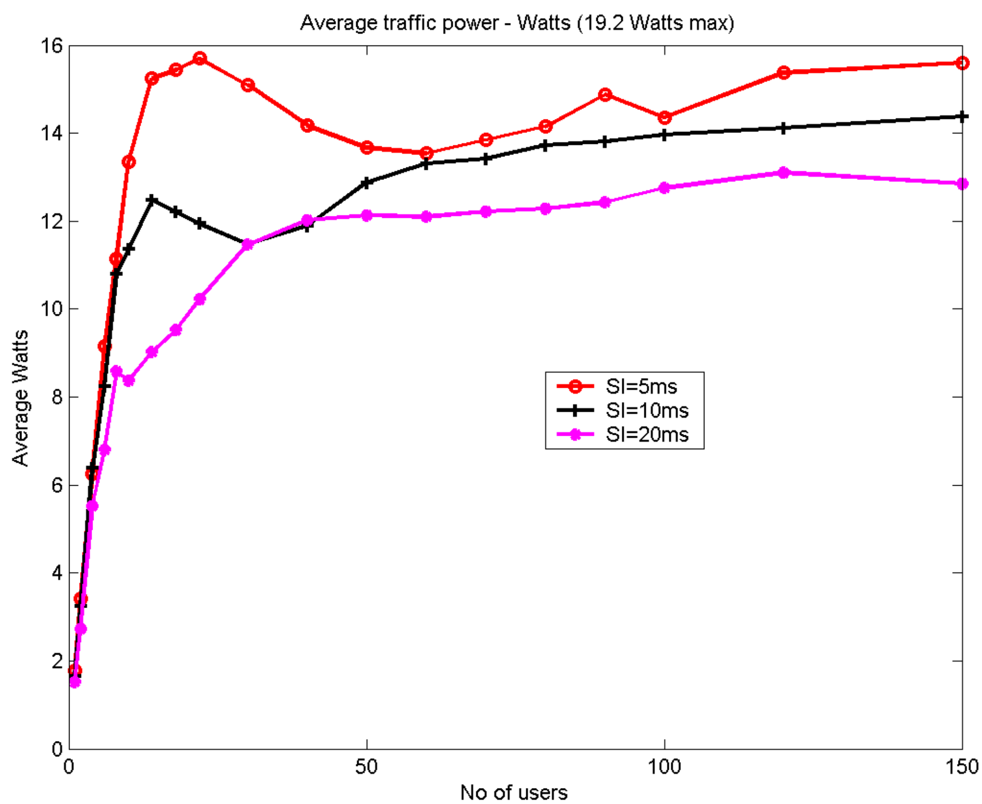

Figure 6.15 : MaxPower EDF Average Power vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 6.15 shows the average power vs. offered load for different scheduling intervals for a delay threshold of 500ms. The power is utilized more when the scheduling interval is less ie.5ms. From the Figure 6.15 it is clear that as scheduling interval increases from 10ms to 20ms the average power gradually decreases, thus saving slot power. For the load of 150 users when SI is 5ms the throughput/watt is around 64.51 b/s/w, as SI increases to 10ms the bit rate/watt is around 48.27 b/s/w. For SI=20ms the bit rate/watt decreases to 30.76 b/s/w.

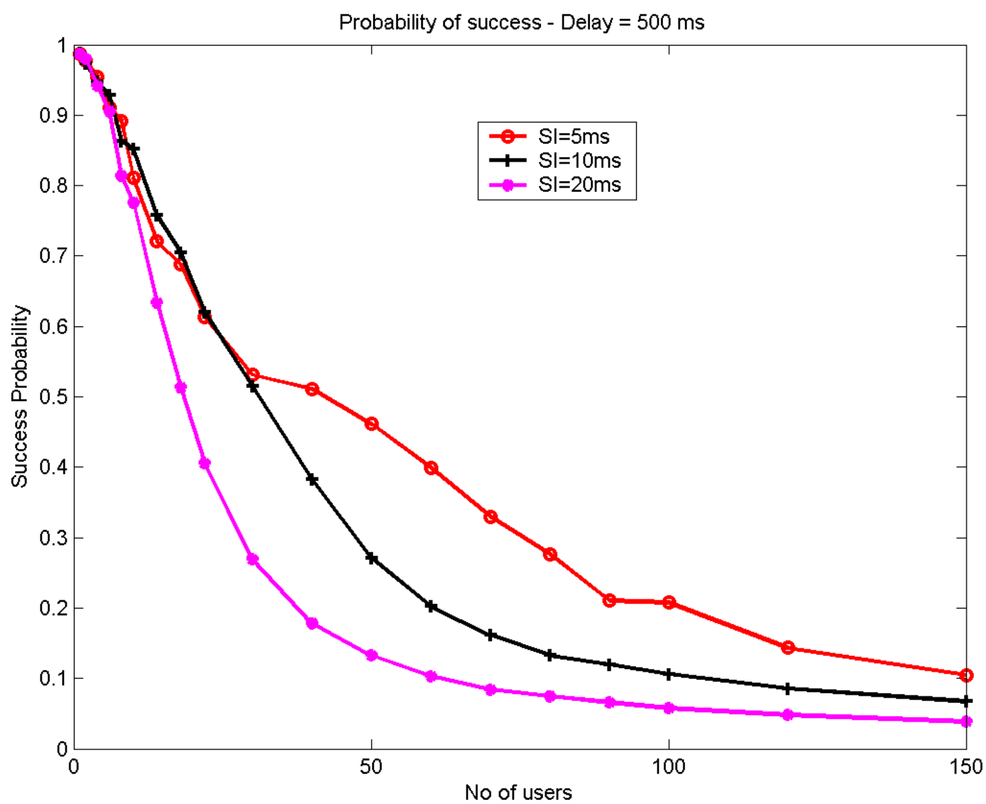

Figure 6.16 : MaxPower EDF Success Prob. vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 6.16 shows the success probability vs. offered load for different scheduling intervals for a delay threshold of 500ms.The success rate for the scheduling interval of 5ms is very large thus serving more number of users in the system. It can be observed from the Figure 6.16 that as the Scheduling interval increases from 10ms to 20ms, thus the success rate decreases steeply and becomes equal to the success rate of EDF. The arrivals happening in the 5ms-scheduling interval is less so they are being served faster due to less packet delays, thus serving more packets in that scheduling interval. An increase in scheduling interval increases the arrivals accumulating in that slot duration. This has an effect in increasing the packet delays and results into more number of packets discarded due to the restriction of delay threshold.

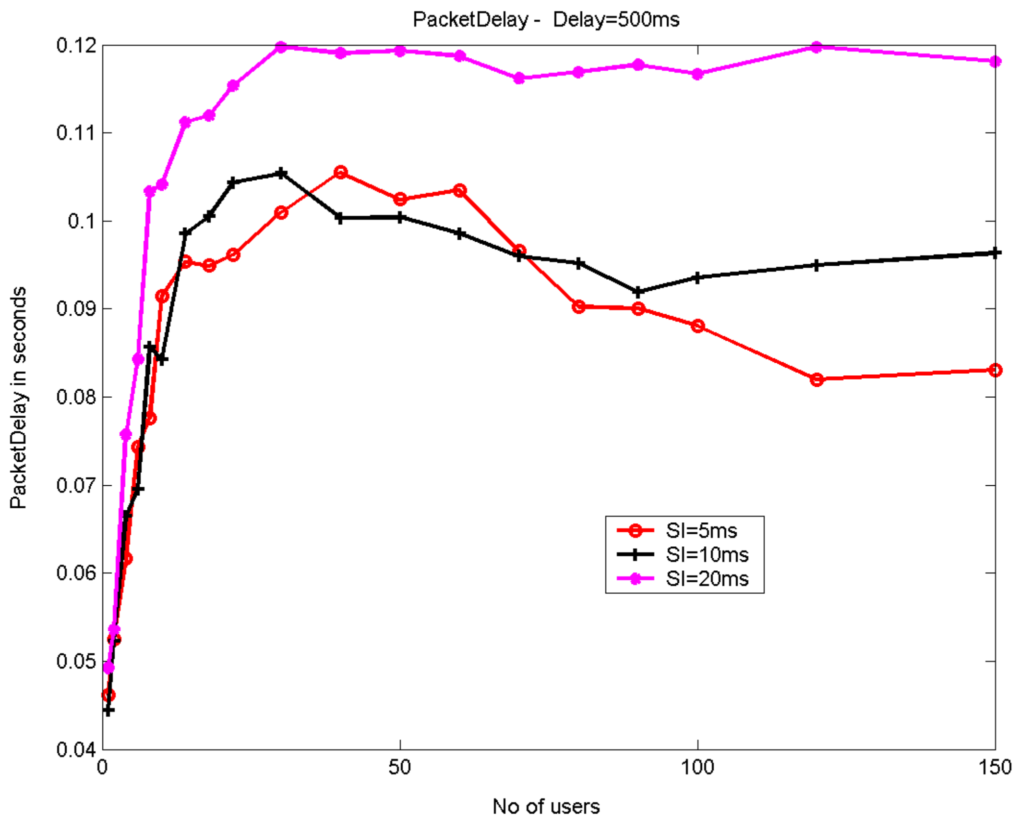

Figure 6.17: MaxPower EDF Packet Delay. Vs. Offered load for SI = 5, 10, 20 ms and D_{th}=500ms

Figure 6.17 shows the packet delay vs. offered load for scheduling intervals 5ms, 10ms and 20ms with a delay threshold of 500ms. The packet delays of MaxPower EDF algorithm increases as scheduling interval increases from 5ms to 20ms.

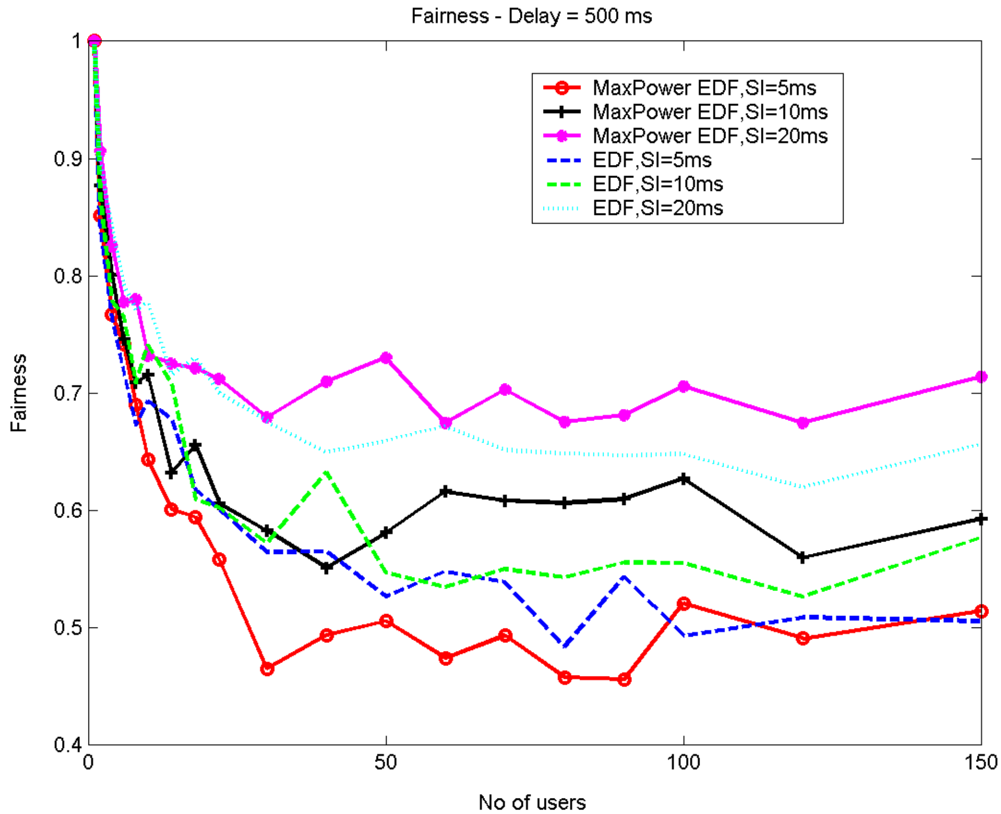

Figure 6.18: MaxPower EDF Fairness. Vs. Offered load for SI = 5, 10, 20 ms and Dth=500ms

Figure 6.18 shows the fairness vs. offered load for scheduling intervals 5ms, 10ms and 20ms and for a particular delay threshold 500ms. The fairness for the load of 150 users at SI=20ms is around 72% for MaxPower EDF whereas the fairness for EDF is around 65% for the same offered load.

In EDF, the head-of-queue (HOQ) packet of each queue is compared to determine which comes first and is scheduled according to earliest deadline. This order is fixed, and if a connection goes into bad state it will have to wait until it comes out of bad state and the other HOQ packets are served first. The second packet in the same queue faces the same challenge. Thus making users to starve till the connection changes to good state. MaxPower EDF is better as the packets are sorted in every slot. Hence if the connection goes in a bad state, in the next slot the next user packet may get scheduled because of maximum power. The fairness for smaller SI is less as the fairness depends on throughput. Since throughput increases as SI increases the fairness also increases.

6.3 MaxPower PEDF Performance under different Scheduling Intervals

6.3.1 Comparison results of PEDF vs. MaxPower PEDF for Scheduling Interval=5ms

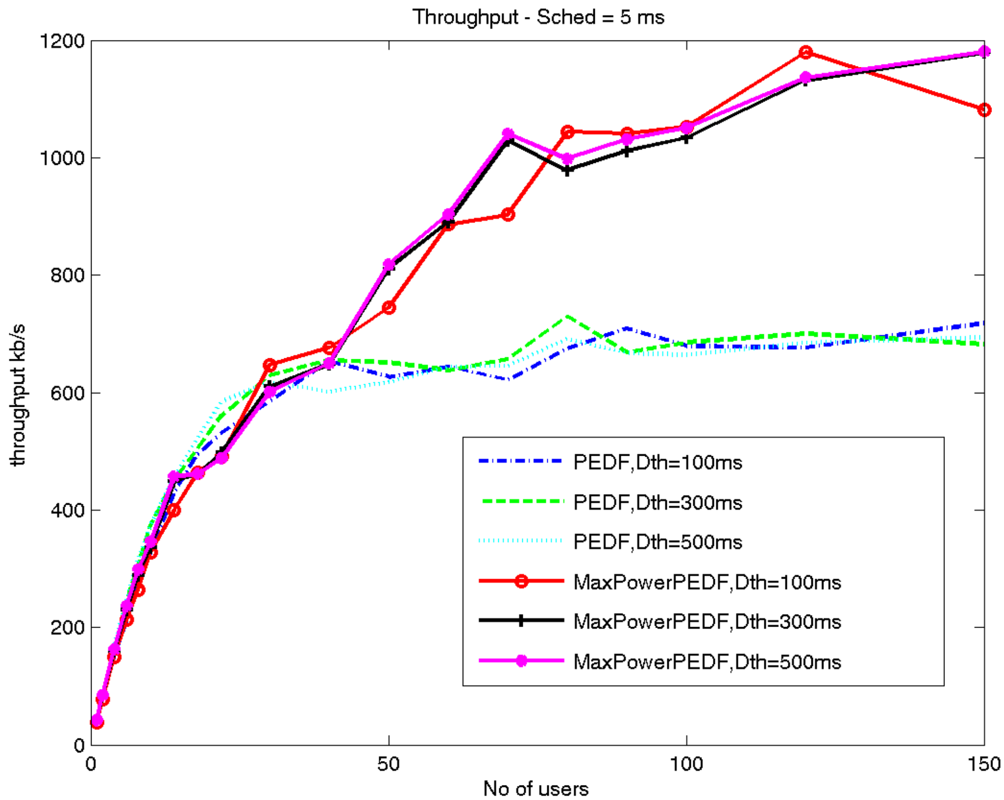

Figure 6.19: MaxPower PEDF Throughput vs. Offered load for sched=5ms

Figure 6.19 demonstrates the throughput against the offered load. The throughput increases in MaxPower PEDF algorithm as the maximum power packet is being served. The maximum power packet has the highest bit rate due to the large packet size. On the other hand, the throughput of PEDF algorithm stabilizes as it gives priority to the earliest deadline packet irrespective of power and distance. For example, the throughput achieved by MaxPower EDF algorithm for 150 users is approximately 1200 kb/s when compared to PEDF algorithm, which achieves the throughput of approximately 600kb/s, which means of 100% increase.

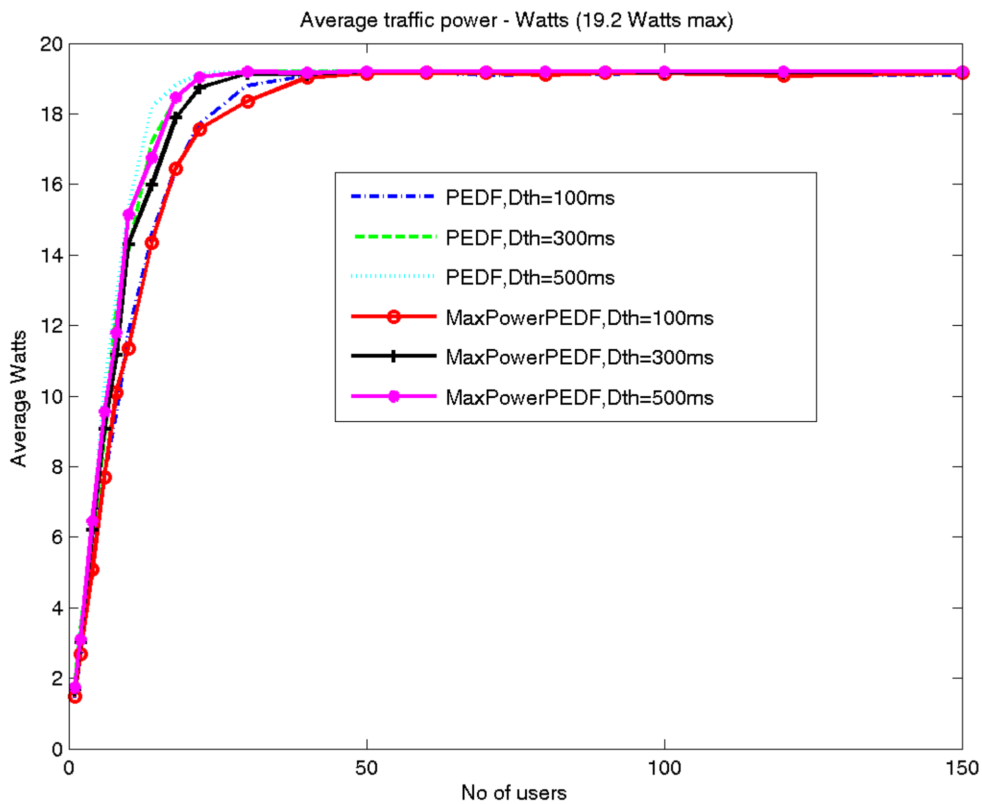

Figure 6.20: MaxPower PEDF Average Power vs. Offered load for sched=5ms

Figure 6.20 demonstrates the average power against offered load. The average traffic power utilized remains the same in both the algorithms. In both the algorithms multiple packets are being served per slot thus utilizing the maximum slot power. For example at load 30 users as the delay threshold increases the power utilization also increases. As the delay threshold increases more packets are served therefore it requires more power.

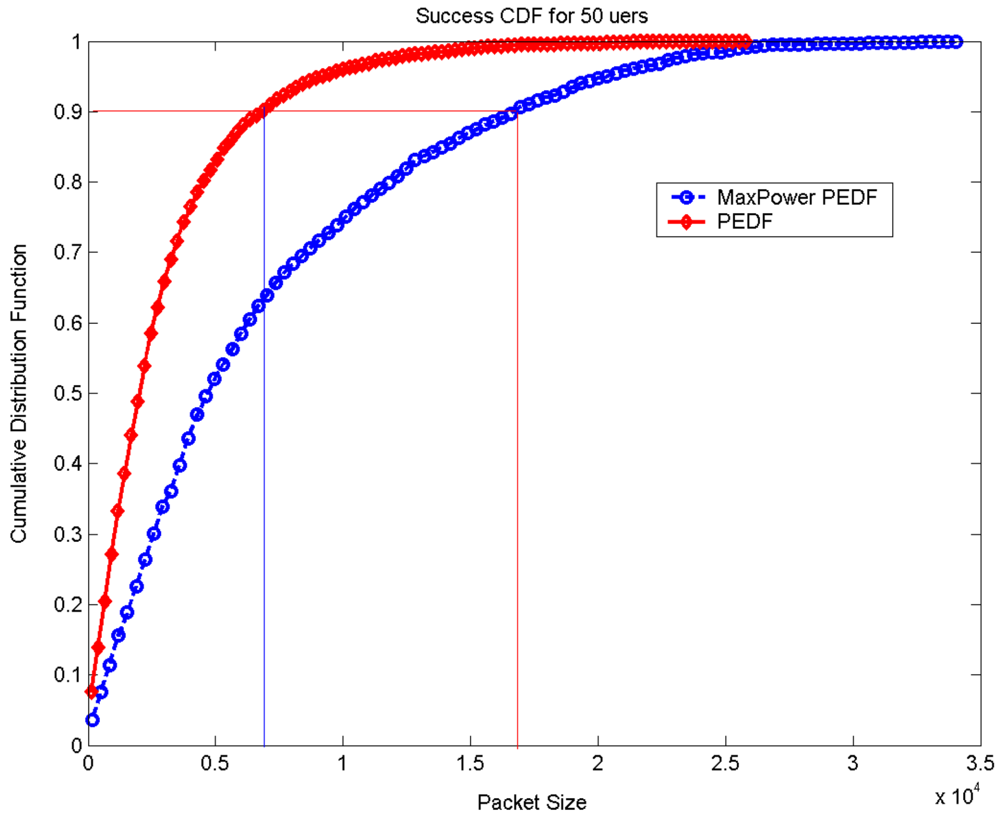

Figure 6.21: MaxPower PEDF Success CDF vs. packet size

Figure 6.21 demonstrates the CDF for PEDF algorithm and MaxPower PEDF algorithm. It is clear from the Figure 6.21 that MaxPower PEDF algorithm is using large packet size than PEDF algorithm. It is observed that 90% of the packets in MaxPower PEDF algorithm simulation use less than 7000 bits packet size where as PEDF algorithm utilizes less than 17000 bits.

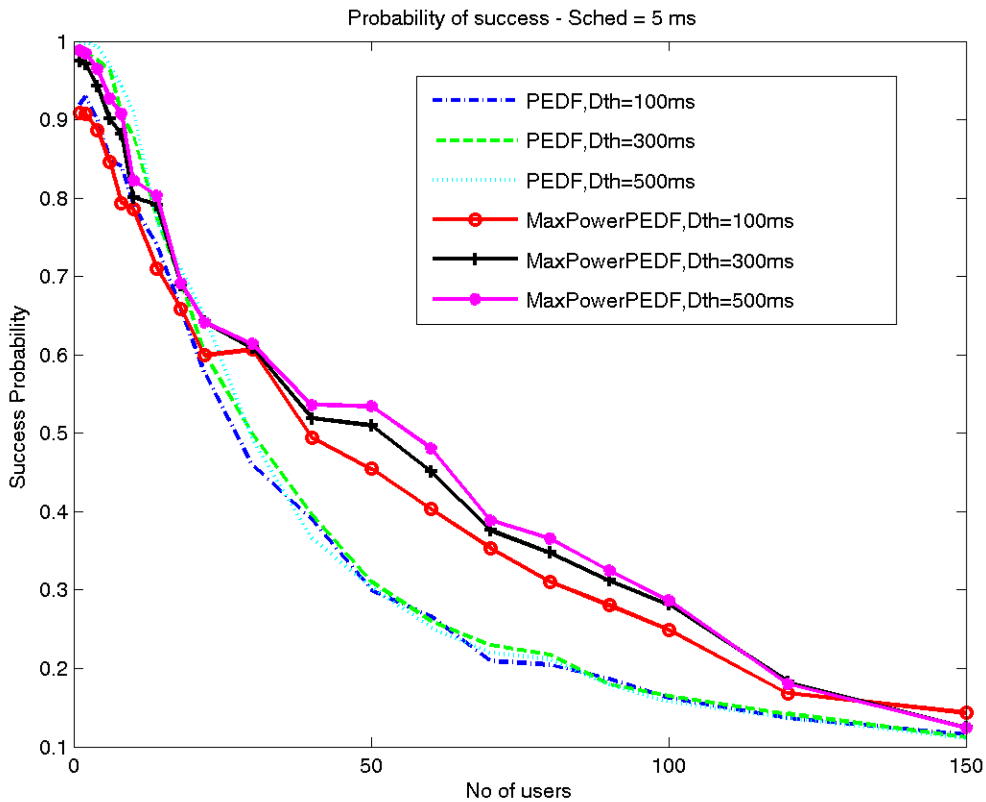

Figure 6.22: MaxPower PEDF Success Probability vs. Offered load for sched=5ms

Figure 6.22 demonstrates the success probability vs. offered load. The success probability for MaxPower PEDF algorithm is slightly greater than the PEDF algorithm. The success rate becomes almost equal to PEDF for large number of users.

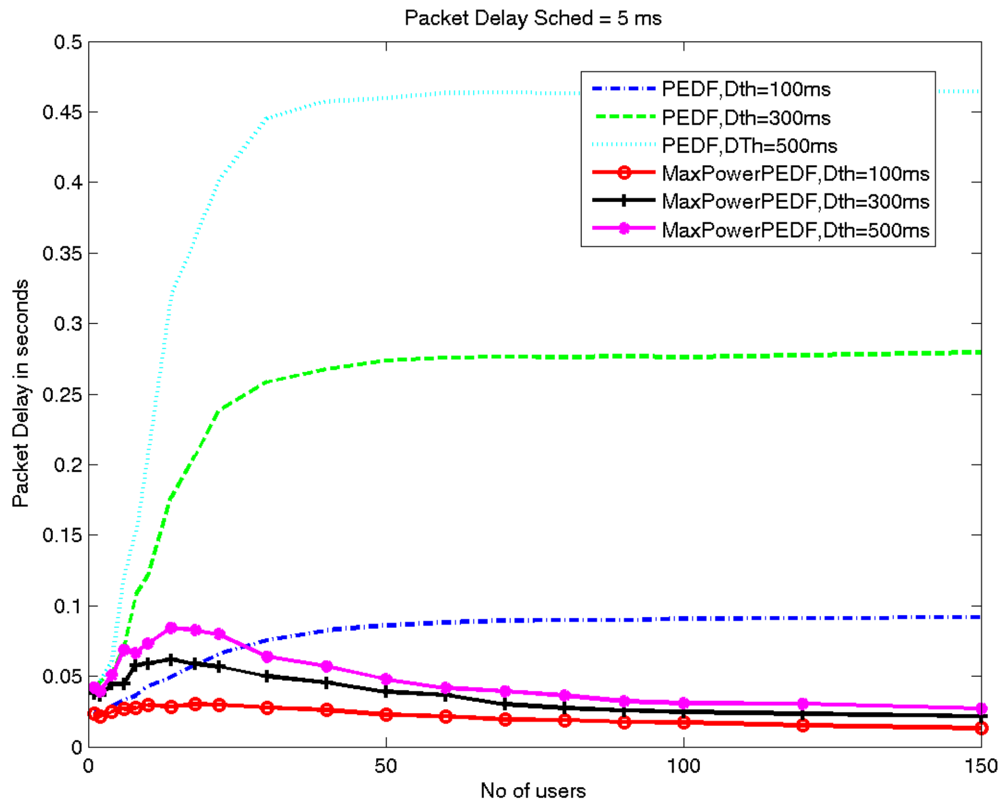

Figure 6.23: MaxPower PEDF Success Packet Delay vs. Offered load for sched=5ms

Figure 6.23 shows the packet delay vs. offered load for a scheduling interval 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower PEDF algorithm are 82.2% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm, the packets are served according to their arrival times.

Table 6.4 summarizes the percentage comparison of throughput, average power and success probability between MaxPower PEDF and PEDF at SI=5ms for the load of 50 users.

Table 6.4: Comparison of PEDF vs. MaxPower PEDF at SI=5ms for 50 users

PEDF vs. MaxPower PEDF (SI=5ms for 50 users)							
	Throughput (kbps)			Average Power (watts)	Success Probability		
Dth (ms)	PEDF	MaxPower PEDF	%	Total slot power is utilized in both algorithms	PEDF	MaxPower PEDF	%
100	620	750	20.96▲		0.31	0.45	45.1▲
300	650	800	23.07▲		0.30	0.5	66.6▲
500	610	810	32.7▲		0.29	0.55	89.6▲

6.3.2 Comparison results of PEDF vs. MaxPower PEDF for Scheduling Interval=10ms

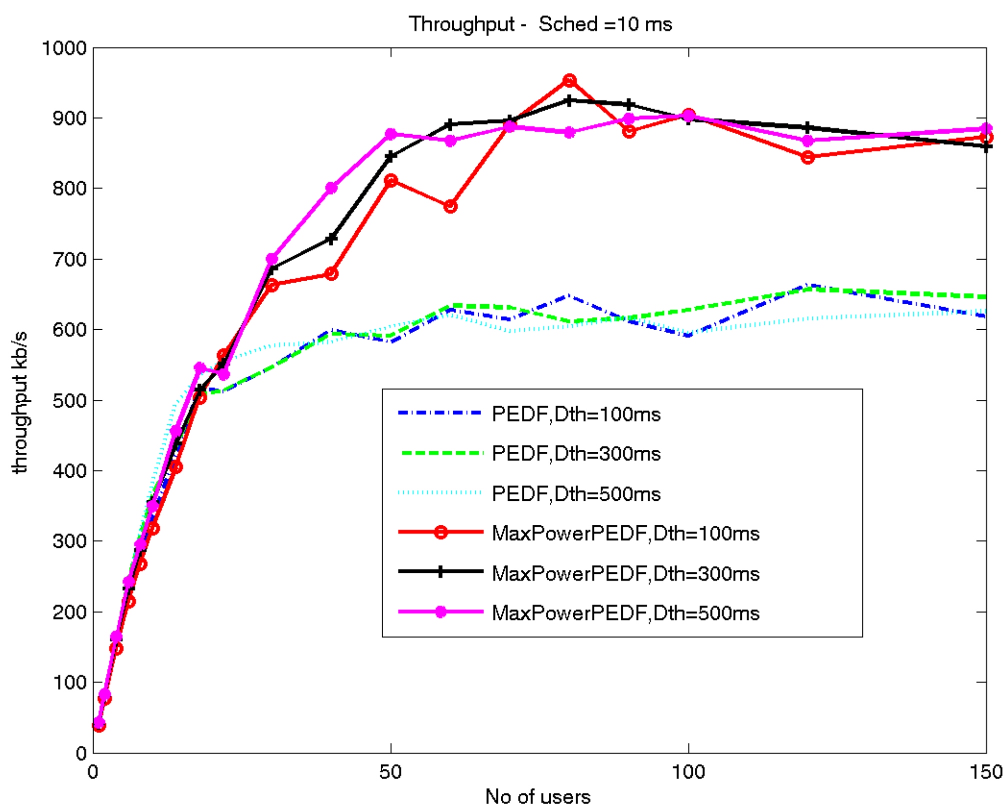

Figure 6.24: MaxPower PEDF Throughput vs. Offered load for sched=10ms

Figure 6.24 demonstrates the throughput vs. offered load for a scheduling interval of 10ms and delay thresholds of 100ms, 300ms and 500ms. The throughput increases for the

MaxPower PEDF algorithm as the maximum power packets are served in each slot till the slot power is reached. In PEDF algorithm, the packets served are according to the earliest deadline packet until the total slot power is utilized irrespective of power and distance. The throughput achieved for MaxPower PEDF algorithm is approximately 900kb/s when compared to PEDF algorithm, which achieves approximately 600kb/s, which is a 50% increase.

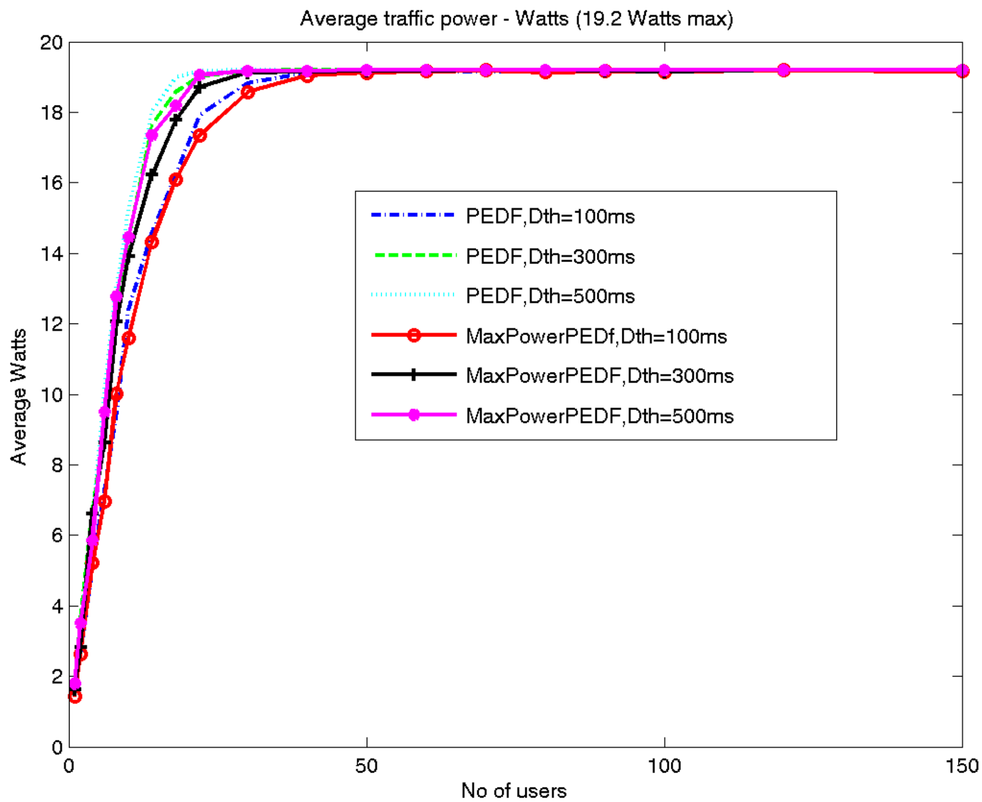

Figure 6.25: MaxPower PEDF Average Power vs. Offered load for sched=10ms

Figure 6.25 demonstrates the average power against the offered load. In MaxPower PEDF algorithm, multiple packets are served in each slot thus utilizing the total traffic power of the slot as done in the PEDF algorithm. Thus, the total traffic power is utilized in both the algorithms to serve packets in each slot.

As the delay threshold increases the power utilization also increases at the load of 30 users. As the delay threshold increases more packets are served therefore require more power.

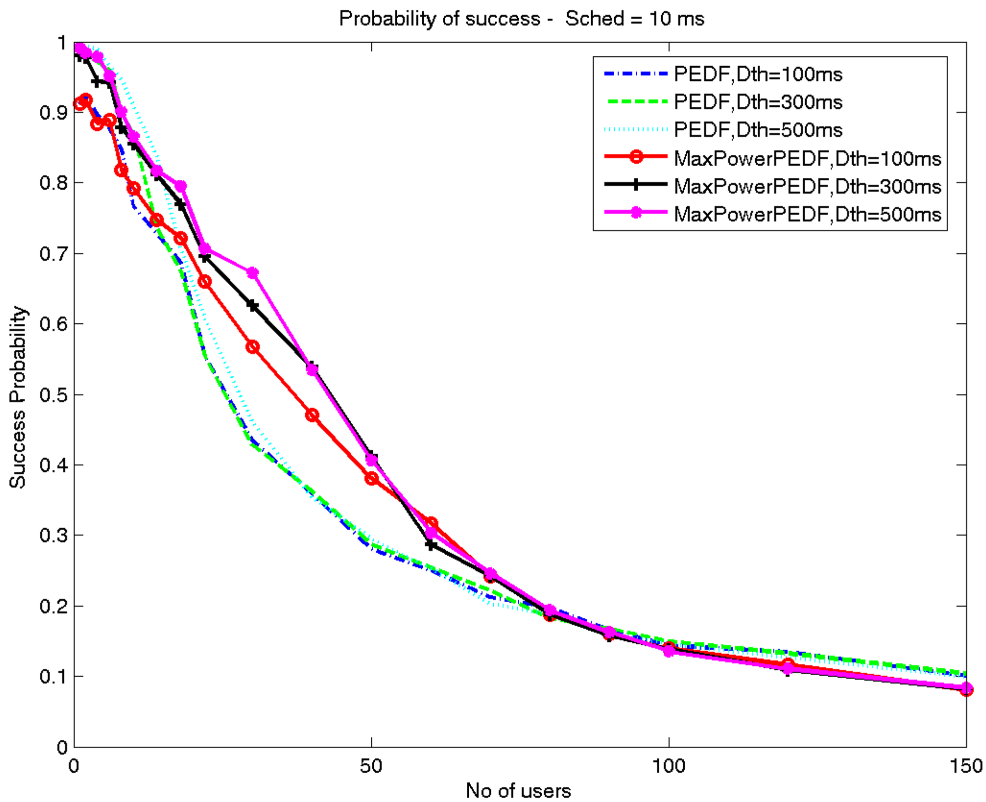

Figure 6.26: MaxPower PEDF Success Probability vs. Offered load for sched=10ms

Figure 6.26 shows the success probability against the offered load. The success probability of MaxPower PEDF algorithm is almost the same as PEDF algorithm. The success rate of MaxPower PEDF starts getting low as the load exceeds 80 users. This is due to the fact that more packets are partially served and thus the success rate decreases where as PEDF algorithm serves according to deadline irrespective of the power and bit rate.

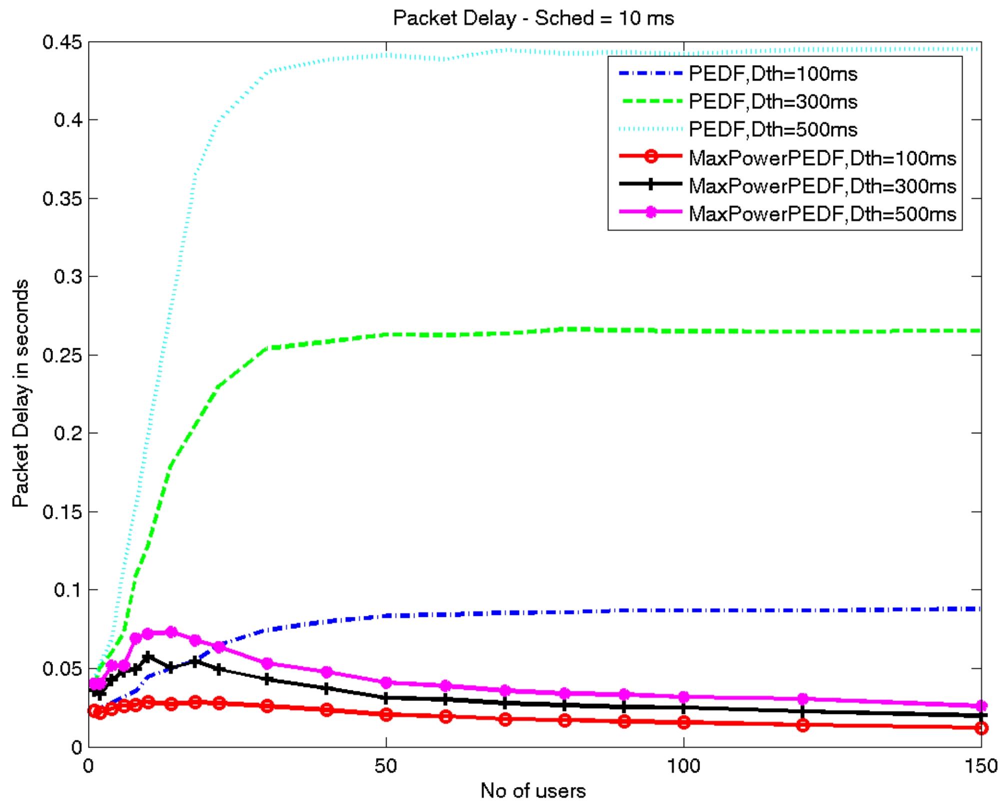

Figure 6.27: MaxPower PEDF Packet Delay vs. Offered load for sched=10ms

Figure 6.27 shows the packet delay vs. offered load for a scheduling interval 10ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower PEDF algorithm are 84.8% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm the packets are served according to their arrival times.

Table 6.5 summarizes the percentage comparison of throughput, average power and success probability between MaxPower PEDF and PEDF at SI=10ms for the load of 50 users.

Table 6.5: Comparison of PEDF vs. MaxPower PEDF at SI=10ms for 50 users

PEDF vs. MaxPower PEDF (SI=10ms for 50 users)							
	Throughput (kbps)			Average Power (watts)	Success Probability		
Dth(ms)	PEDF	MaxPower PEDF	%		PEDF	MaxPower PEDF	%
100	580	800	37.9▲	Total slot power is utilized in both algorithms	0.28	0.38	35.7▲
300	595	850	42.8▲		0.29	0.41	41.3▲
500	596	870	45.9▲		0.27	0.42	55.5▲

6.3.3 Comparison results of PEDF vs. MaxPower PEDF for Scheduling Interval=20ms

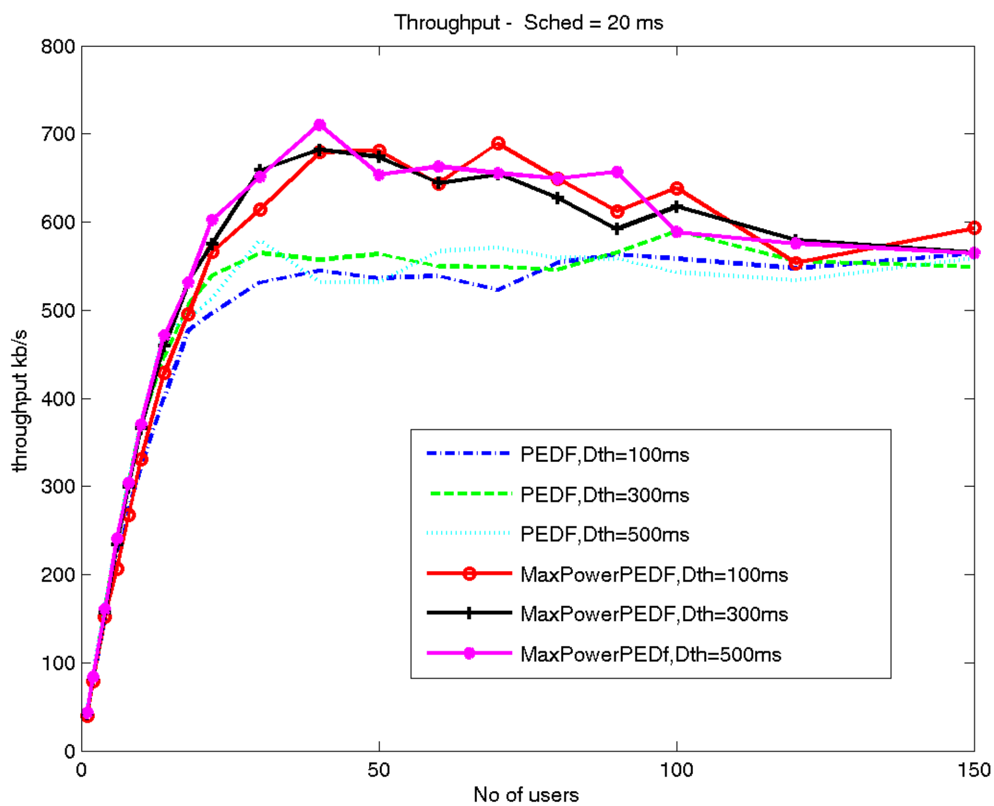

Figure 6.28: MaxPower PEDF Throughput vs. Offered load for sched=20ms

Figure 6.28 demonstrates throughput vs. offered load for a scheduling interval of 20ms and delay thresholds 100ms, 300ms and 500ms. In MaxPower PEDF algorithm, the throughput increases initially and then decreases. This can be attributed to high percentage of partially served packets.

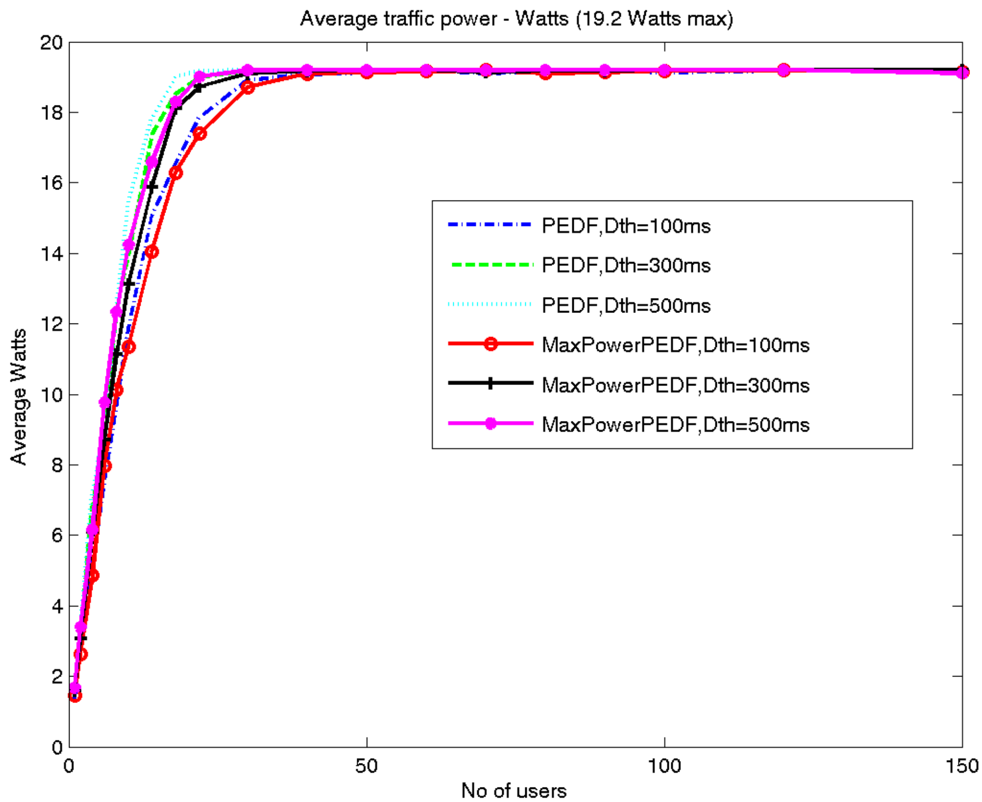

Figure 6.29: MaxPower PEDF Average Power vs. Offered load for sched=20ms

Figure 6.29 demonstrates the average power for a scheduling interval of 20 ms and delay thresholds 100ms, 300ms and 500ms. The average traffic power is same for both the algorithms as multiple packets are being served in each slot. The total slot power is utilized to serve the packets in each slot.

As the delay threshold increases the power utilization also increases at the load of 30 users. As the delay threshold increases more packets are served therefore require more power.

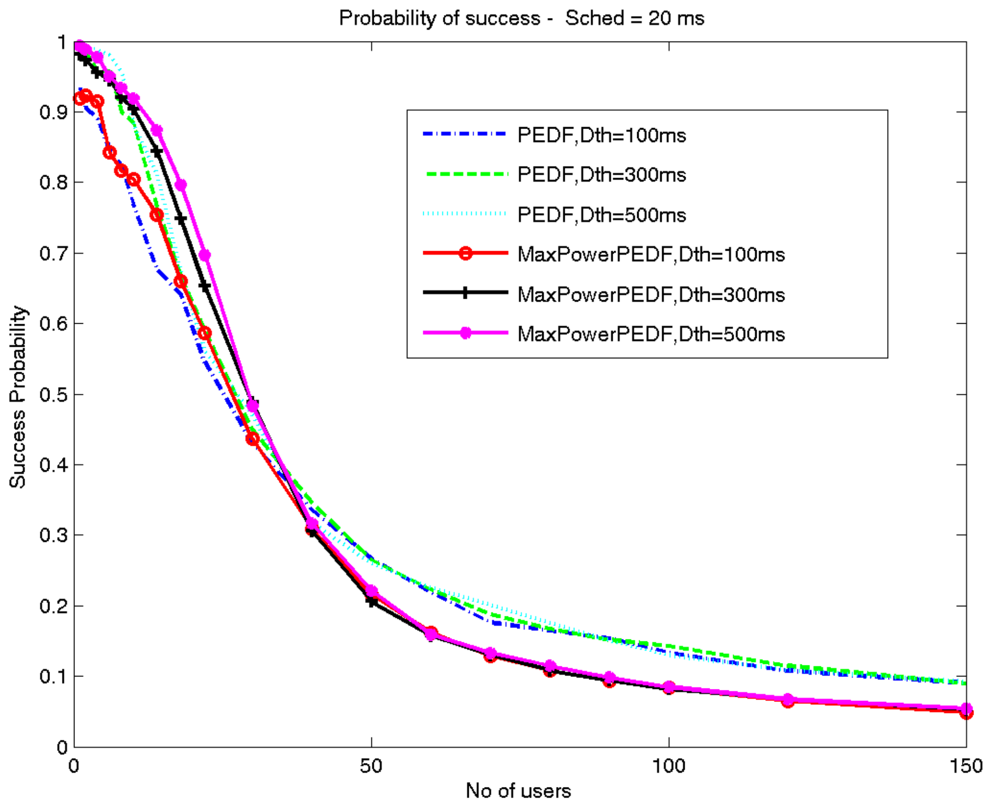

Figure 6.30: MaxPower PEDF Success Probability vs. Offered load for sched=20ms

Figure 6.30 demonstrates the success probability vs. offered load for a scheduling interval of 20ms and delay thresholds 100ms, 300ms and 500ms. The success rate of MaxPower PEDF is lower than the PEDF as more packets are partially served and thus the success rate decreases where as PEDF algorithm serves according to deadline irrespective of the power and bit rate.

Figure 6.31 shows the packet delay vs. offered load for a scheduling interval of 20ms and delay thresholds ranging from 100ms, 300ms and 500ms respectively. The packet delays of MaxPower PEDF algorithm are 85.36% less than PEDF algorithm because fresh packets are being served in that slot. In PEDF algorithm, the packets are served according to their arrival times.

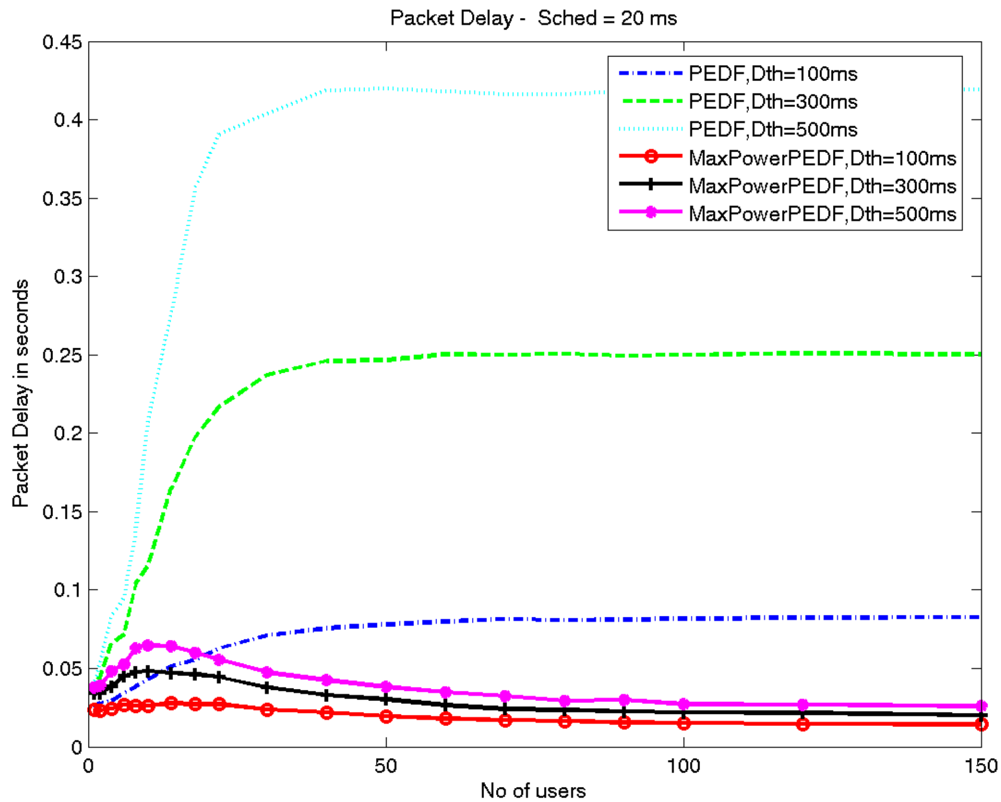

Figure 6.31: MaxPower PEDF Packet Delay vs. Offered load for sched=20ms

Table 6.6 summarizes the percentage comparison of throughput, average power and success probability between MinPower PEDF and PEDF at SI=20ms for the load of 50 users.

Table 6.6: Comparison of PEDF vs. MaxPower PEDF at SI=20ms for 50 users

<table>
<tr><td colspan="8">PEDF vs. MaxPower PEDF (SI=20ms for 50 users)</td></tr>
<tr><td></td><td colspan="3">Throughput (kbps)</td><td>Average Power (watts)</td><td colspan="3">Success Probability</td></tr>
<tr><td>Dth(ms)</td><td>PEDF</td><td>MaxPower PEDF</td><td>%</td><td rowspan="4">Total slot power is utilized in both algorithms</td><td>EDF</td><td>MaxPower PEDF</td><td>%</td></tr>
<tr><td>100</td><td>530</td><td>680</td><td>28.3▲</td><td>0.27</td><td>0.2</td><td>25.9▼</td></tr>
<tr><td>300</td><td>550</td><td>670</td><td>21.81▲</td><td>0.26</td><td>0.21</td><td>19.2▼</td></tr>
<tr><td>500</td><td>510</td><td>650</td><td>27.4▲</td><td>0.26</td><td>0.21</td><td>19.2▼</td></tr>
</table>

6.4 Effect of Scheduling Interval on MaxPower PEDF

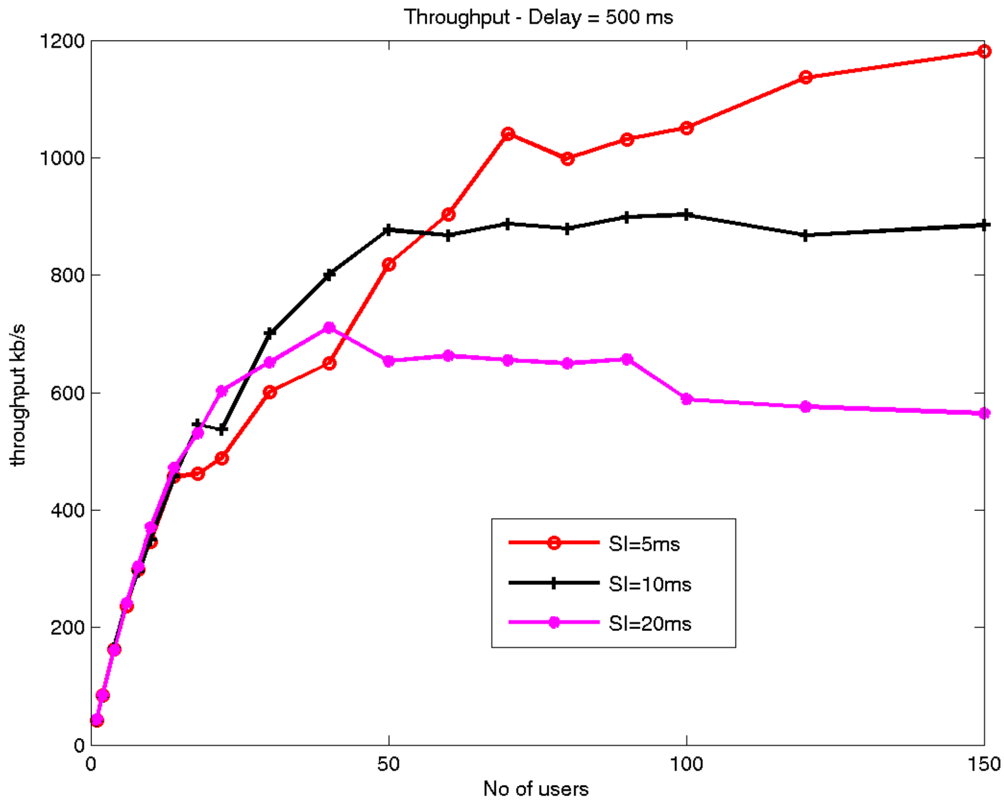

Figure 6.32: MaxPower PEDF Throughput vs. Offered load for sched=5, 10, 20ms and Dth=500ms

Figure 6.32 shows the throughput vs. offered load for different scheduling intervals at a particular delay threshold of 500ms.The above Figure 6.32 shows that as scheduling Interval increases the throughput decreases since throughput is inversely proportional to the scheduling interval. Thus, the results of throughput when scheduling interval is 5ms is very high i.e., the bit rate is good for more number of users but when the scheduling interval increases to 10ms and 20ms it decreases gradually i.e. bit rate decreases as the altered offered load increase. This shows that slot duration plays an important role in supporting good bit rate for the offered load.

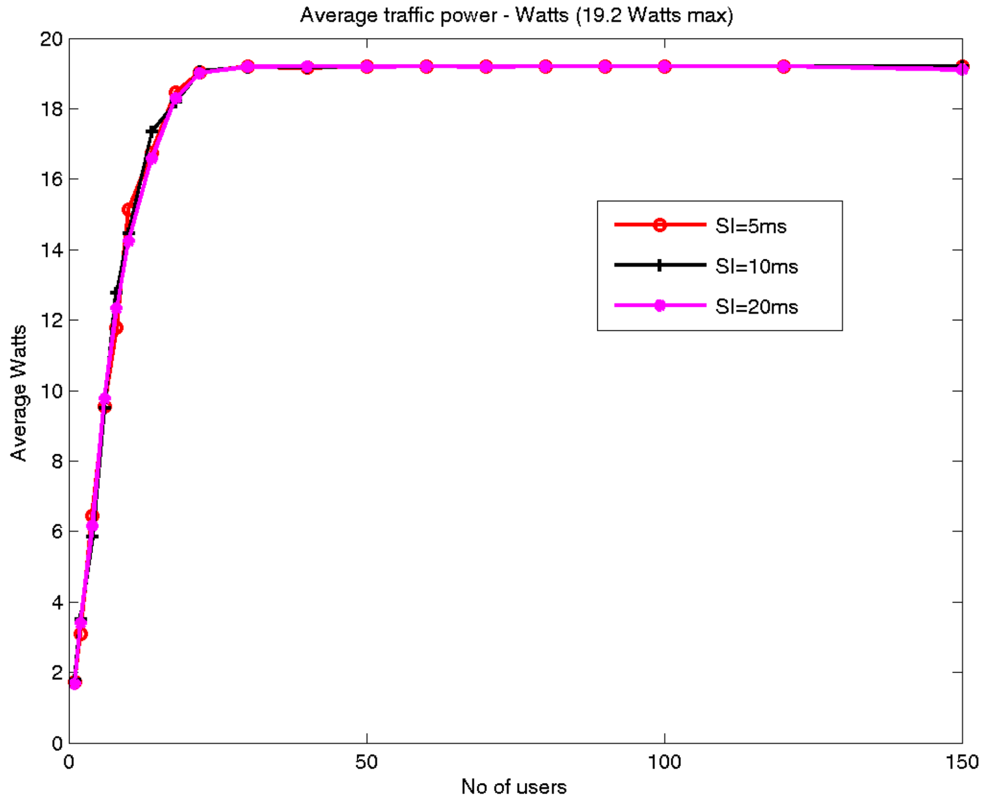

Figure 6.33: MaxPower PEDF Average Power vs. Offered load for sched=5, 10, 20ms and Dth=500ms

Figure 6.33 demonstrates the average traffic power against offered load for different scheduling intervals and a particular delay threshold of 500ms. It can be observed that average power is same for all scheduling intervals. This is because total slot power is utilized for serving multiple packets in the slot.

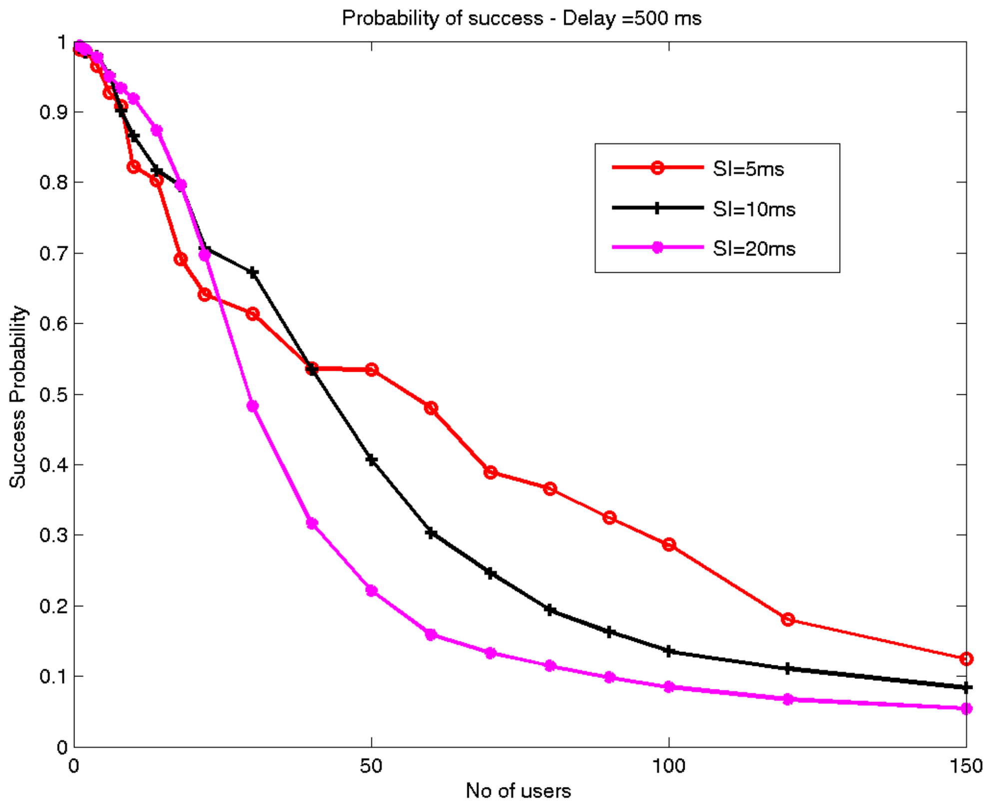

Figure 6.34: MaxPower PEDF Success Prob. vs. Offered load for sched=5, 10, 20ms and Dth=500ms

Figure 6.34 shows the success probability vs. offered load for different scheduling intervals at a particular delay threshold of 500ms.The success rate for the scheduling interval 5ms is better thus serving more number of users in the system. As scheduling interval increases from 10ms to 20ms there is a decrease in success rate which can be observed from the Figure 6.34.The arrivals happening in the 5ms-scheduling interval is less so they are being served faster due to less packet delays since they are less delayed, thus serving more packets in this scheduling interval. An increase in scheduling interval increases the arrivals accumulating in that slot duration. This has an effect in increasing the packet delays and results into more number of packets discarded due to the restriction of delay threshold. The success probability is less for lower number of users because the packets are less to be scheduled but as the load increases the number of packets increases thus increasing the success rate.

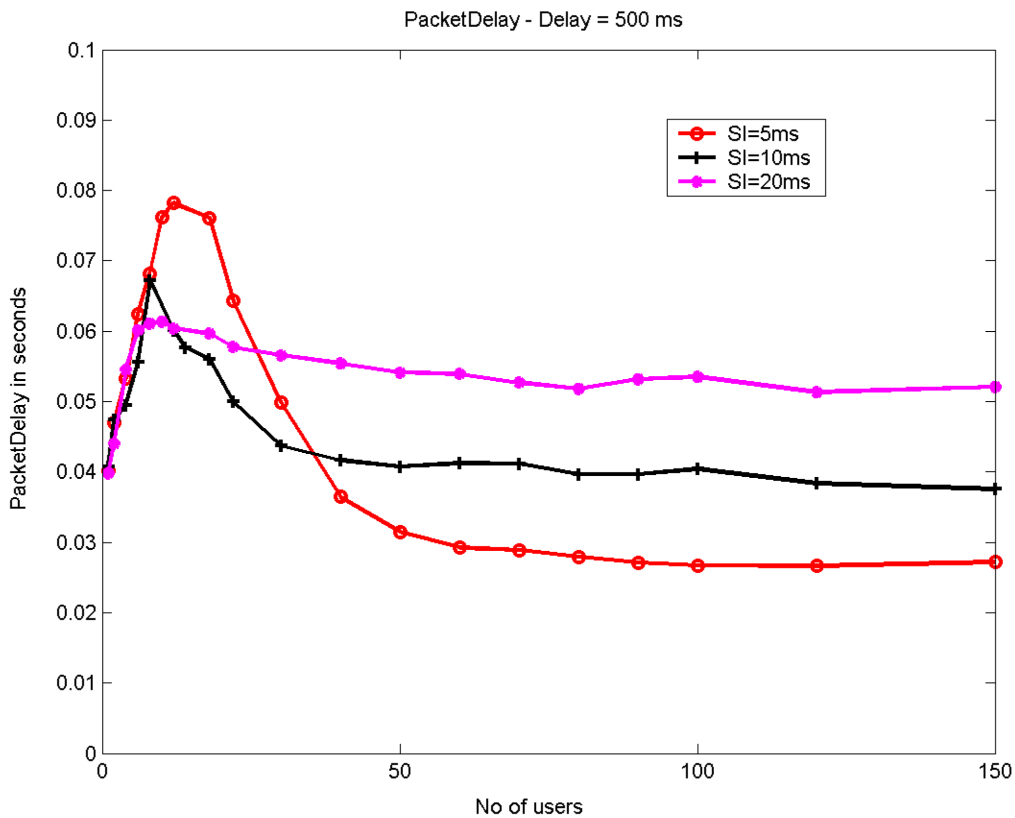

Figure 6.35: MaxPower PEDF Packet Delay. Vs. Offered load for sched=5,10,20ms Dth=500ms

Figure 6.35 shows the packet delay vs. offered load for scheduling intervals 5ms, 10ms, 20ms and particular delay threshold of 500 ms. Packet delays increases as scheduling interval increases.

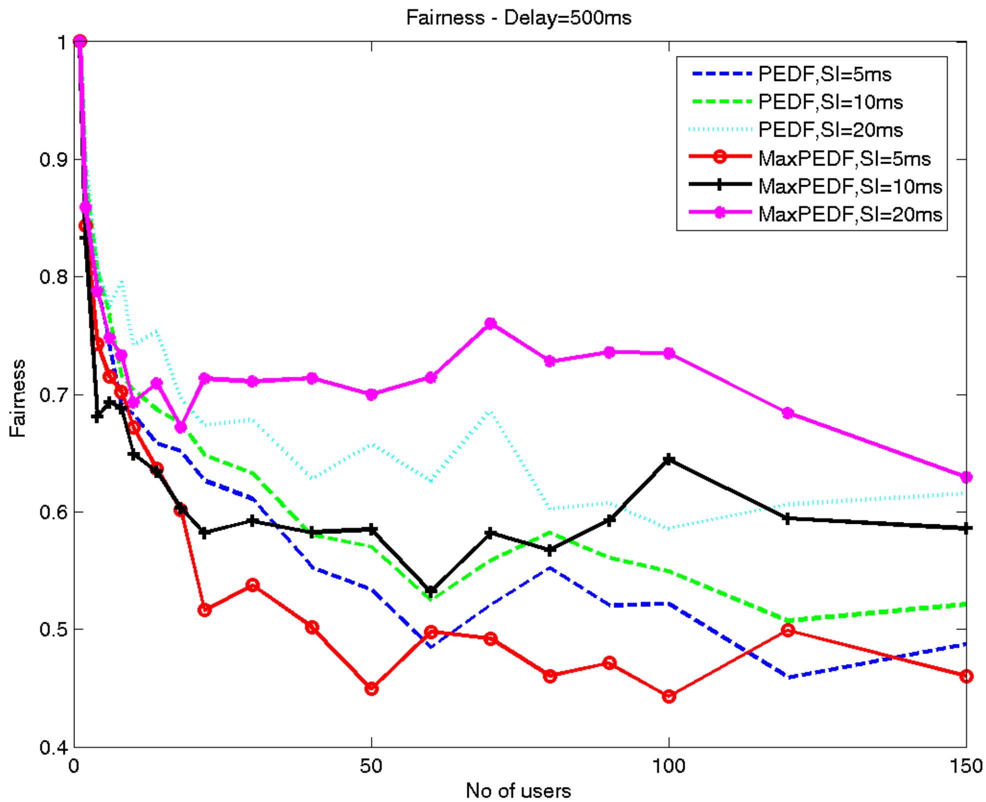

Figure 6.36: Fairness. Vs. Offered load for SI = 5, 10, 20 ms and Dth=500ms

Figure 6.36 shows the fairness vs. offered load for scheduling intervals 5ms, 10ms and 20ms and for a particular delay threshold 500ms. The fairness of MaxPower PEDF algorithm increases as scheduling interval increases from 5ms to 20ms. The fairness for SI=20ms for the offered load of 150 users is 65% for MaxPower PEDF Whereas it reaches around 63% for PEDF at the same offered load.

In PEDF, the head-of-queue (HOQ) packet of each queue is compared to determine which comes first and is scheduled according to earliest deadline. This order is fixed, and if a connection goes into bad state it will have to wait until it comes out of bad state and the other HOQ packets are served first. The second packet in the same queue faces the same challenge. Thus making users to starve till the connection changes to good state.

MaxPower PEDF is better as the packets are sorted in every slot. Hence if the connection goes in a bad state, in the next slot the next user packet may get scheduled because of maximum power.

CHAPTER 7

CONCLUSION

In this chapter, we will present the summary of the work and conclusions of the research. Suggestions for future work of the proposed system are also introduced.

7.1 Summary and Contributions

Efficient scheduling algorithms are necessary to optimize the use of limited radio resources and to provide QoS for subscribers. Burst rate admission and scheduling are two important components in providing the above requirement. In this work we have studied downlink-scheduling algorithms for WCDMA Networks. However, the present work proposed few modified forms of EDF [11] and PEDF [12] algorithms, based on the power of user's packet. Moreover, extensive simulation runs have been conducted to study the effects of different parameters such as Scheduling Interval and Delay Threshold. The performance figures in terms of throughput, average power, Success transmission and Packet discarded were evaluated as a function of the offered load.

MinPower EDF algorithm, MinPower PEDF algorithm, MaxPower EDF algorithm and MaxPower PEDF algorithm are the proposed algorithms in this Thesis. These proposed algorithms are compared with the EDF and PEDF algorithms in terms of throughput, average power, success probability and fairness. Some of the advantages and drawbacks are summarized below.

7.1.1 Advantage of MinPower EDF

The main advantage of Minimum Power EDF over EDF is more successful transmission of packets in slots, thus increasing the success rate in our proposed algorithm i.e., MinPower EDF as against EDF algorithm. From the Table 5.3 it is clear that the success rate of MinPower EDF over EDF is 100% high for SI=20ms for the load of 50 users

7.1.2 Disadvantage of MinPower EDF

The main disadvantage of this algorithm is that it serves smaller packets. This is due to the fact that as the load increases which leads to drop in the aggregate throughput. From the Table 5.3 it is clear that the throughput of MinPower EDF over EDF is 73.13% lower for SI=20ms for the load of 50 users

7.1.3 Advantage of MinPower PEDF

In this algorithm, the packet transmission success is more as there is a probability of serving more number of minimum power packets in the given time slot. As this algorithm serves multiple packets thus utilizing the total slot power. Thus the throughput increases by serving more number of packets. From the Table 5.6 it is clear that the success rate of MinPower PEDF over PEDF is 126.9% higher for SI=20ms for the load of 50 users.

7.1.4 Disadvantage of MinPower PEDF

The main disadvantage of this algorithm is that it serves smaller packets. Hence as the load increases we noticed a drop in the aggregate throughput. From the Figure 5.28 it is clear that the throughput of MinPower PEDF over PEDF is 18.18% lower for SI=20ms for the load of 150 users

7.1.5 Advantage of MaxPower EDF

The main advantage of this algorithm is that larger packets are scheduled. From the Table 6.3 it is clear that the throughput of MaxPower EDF over EDF is 41.7% higher for SI=20ms for the load of 50 users.

7.1.6 Disadvantage of MaxPower EDF

The main disadvantage of this algorithm is that the success rate is lower than EDF algorithm due to partial serving of packets. From the Table 6.3 it is clear that the success rate of MaxPower EDF over EDF is 4.1% lower for SI=20ms for the load of 50 users.

7.1.7 Advantage of MaxPower PEDF

The main advantage of this algorithm is that larger packets are scheduled. From the Table 6.6 it is clear that the throughput of MaxPower PEDF over EDF is 27.4% higher for SI=20ms for the load of 50 users.

7.1.8 Disadvantage of MaxPower PEDF

The main disadvantage of this algorithm is that the success rate is lower than PEDF algorithm due to partial serving of packets. From the Table 6.6 it is clear that the success rate of MaxPower EDF over EDF is 19.2% lower for SI=20ms for the load of 50 users.

Using Jains Fairness Index we have studied the fairness of MinPower EDF algorithm and MinPower PEDF algorithm. In MinPower EDF for 150 users the fairness is reached to about 71% for SI=20ms. In MinPower PEDF for 150 users the fairness is reached to about 68% for SI=20ms. On the other hand in MaxPower EDF for 150 users the fairness is reached to about 50% for SI=20ms. In MaxPower PEDF for 150 users the fairness is reached to about 63%.

7.2 Future Work

The results obtained in this work, which are the enhancement of the continuous bit rate algorithm serving single packet per slot, and also multiple packets per slot. Our proposed algorithms MinPower EDF and MinPower PEDF showed sensitivity to the parameters such as Scheduling Interval and Delay Threshold. We have contributed in this area with many new approaches but we believe that more work can be done to improve this work.

This work can be applied to discrete rates to see the effect of scheduling interval and delay threshold on performance parameters such as throughput, average power, success rate and discard rate.

This work studied assuming *a 19-cell CDMA network layou*t. The mobile terminals are stationary i.e. no mobility is considered. This is considered as recommendation for further research. This work can be extended to see the effect on mobility, which affects the Qos parameters.

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