Online Scheduling Algorithms for CDMA Data Networks

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Abstract

Future wireless networks will be dominated by heterogeneous packet data services. To provide wide a variety of Quality-of-Service (QoS) for this traffic efficient scheduling algorithms are necessary. Due to the nature of wireless channels, offline scheduling algorithms are infeasible in wireless communications. Moreover, computationally offline optimal algorithm problem is an NP-hard; rendering online algorithm is the only solution. Primary goal of this paper is to show that greater details about user's request in *online scheduling algorithm* can make the algorithm closer to the optimal offline algorithm. Powered Earliest Deadline First (PEDF) and Earliest Deadline First (EDF) are the two important online scheduling algorithms for CDMA. As PEDF uses little more information than EDF, it performs better than EDF and closer to optimal offline algorithm. This is will be done through simulation and some reference results. This paper will also show the impact of *scheduling interval* and *delay threshold* in scheduling algorithms. All of these will be based on CDMA data networks.

1. Introduction

Traffic in future wireless networks is expected to be a mix of real-time and non-real time data-traffic, with users desiring diverse QoS guarantees for different types of traffic. On the other hand CDMA will be the widely deployed air interface for next generation wireless networks [1]. So for CDMA data networks, traffic scheduling algorithms are highly necessary for efficient management of resources and to provide a broad range of QoS guarantees.

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 [2]. A traffic scheduling algorithm has to satisfy three essential attributes to be used in data network: low end-to-end delay, good fairness and simplicity of implementation complexity. Scheduling algorithms can be classified in different ways depending on the main serving criteria. In terms of way of information gathering for making scheduling decision scheduling algorithms can be *Offline and Online*. An **offline** algorithm knows about all requests and all channel capacities for all time. Based on all these information it does the scheduling. On the other hand **online** algorithm knows about requests and capacities those have arrived up to previous or at best current time slot. Online algorithm is the reality. As offline algorithm knows all the future states that's why it is the optimal algorithm and it is used to judge the online algorithms [1]. If we can gather more information about user's request we can make the algorithm more close to optimal (offline) algorithm.

There are some widely discussed online scheduling algorithms for CDMA, like Processor Sharing (PS) based *GPS (General Processor Sharing*), Deadline based *Earliest Deadline First (EDF)* [3].Rate processor sharing was proposed in [4] for scheduling in the downlink, followed by further work [5].In [3] downlink scheduling like EDF (Earliest Deadline First) in CDMA data networks has been discussed and different scheduling metrics have been proposed for these scheduling algorithms. EDF has been modified in [6] as PEDF (Powered EDF) to support more than one user in each time slot. Further PEDF outperformed by proposed HOLPRO (Head of Line PsuedopRObability) in [7]. An optimal transmission scheduling for the non-real time traffic in CDMA system, to reduce the transmission time span, and thereby increase the radio network capacity has been discussed in [8].An extension of [1] with some realistic considerations like variable channel conditions has been done in [9]. A new scheduling algorithm PDSTTF (Prediction based Delay-Constrained Shortest Transmission Time First) and its modified version M- PDSTTF that utilizes the delay bound, packet size and rate information has been proposed in [10].

Primary goal of this paper is to show that greater details about user's request for online algorithm can make it comparable to optimal offline algorithm. This will be done through simulation and some reference results. It will also present the impact of scheduling interval and delay threshold in scheduling algorithms. All of these will be based on CDMA data networks.

The organization of the paper is as follows. A brief description of some deadline based online algorithms will be presented in section 2. Simulation and Modeling will be described in Section 3. The results and discussion are presented in Section 4.And conclusion will be in the final Section 5.

2. Online Scheduling Algorithms for CDMA

With the growing interest in the integration of real-time and non-real time traffic in telecommunication networks, CDMA appearing as the most wireless access method of choice. Integration of various types of traffic in CDMA is simpler than other access schemes like TDMA (Time Division Multiple Access) or FDMA (Frequency Division Multiple Access) as it does not require any specific coordination among users. For this reason next generation wireless communication is shifting to CDMA based technology

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[11].We have major two resources for wireless communications, power and the bandwidth. These are limited for their respective reasons. ***Scheduling*** is necessary for efficient utilization these limited resources.

The wireless channels are prone to errors and their state varies randomly in time on both a slow and a fast time scales due to slow and fast fading respectively. For these reasons scheduling in wireless is very complex and critical than wireline. Due to fast variation of channel conditions it is quite impossible to collect channel's future status even for next second. So offline algorithm is not practical for wireless communication even for wired. Again computationally offline optimal algorithm problem is NP-hard [1]. In this case online algorithm is the only solution and to optimize the online algorithm, we need to provide the scheduler as much as information possible.

An online scheduling algorithm knows about requests those have arrived up to current time slot and the channel capacities from the BS to the different mobiles during the time slot. Based on this information, it makes a decision about which request to schedule during the time slot. *Processor sharing (PS)* and *deadline based (EDF)* are the two widely discussed online algorithms for downlink scheduling in CDMA data networks [3].

- ***Processor sharing (PS):*** General Processor GPS is an efficient, flexible, and fair scheduler originally proposed for use in an error-free environment.
- ***Deadline based (EDF):*** It is also know as Earliest Due Date (EDD). It assigns all the power to the user for which the deadline of the packet at the head of queue is closest [3].

This paper will focus only on the deadline based algorithms. Some of the important deadline based scheduling algorithms are:

- Earliest Deadline First (EDF)
- Powered Earliest Deadline First (PEDF)
- Head of Line PsuedopRObability(HOLPRO)
- Prediction based Dealy-Constrianed Shortest Transmission Time First (PDSTFF)

For our simulation purpose we will use first two algorithms.

2.1 Earliest Deadline First (EDF)

This is the first deadline-based downlink-scheduling scheme, which utilizes the deadline information of the traffic as the serving criteria. It is also know as Earliest Due Date (EDD). In EDF, during each time slot a user will be selected from the head of queue on the basis of smallest of (t_i - w_i), and that user would be assigned all the power. Therefore, only one user can be served in each slot, which might cause misuse of the power [3] [6]. Scheduling criteria for EDF is as follows:

$$j = \arg\min(t_i - w_i)$$

Where t_i=delay bound or deadline
w_i= waiting time

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2.2 Powered Earliest Deadline First (PEDF)

Power Earliest Deadline First Algorithm (PEDF) is the modified version of the *Earliest Deadline First Algorithm (EDF).* PEDF finds the user with the earliest deadline for the head packet at beginning of a time slot and assigns the required power to it. If there is remaining power, it finds the next user in the same way for this slot; if the remaining power is not enough to serve the whole 2^{nd} packet then it will serve part of offered load with that power. So this approach decides to serve more than one user if the basestation has enough power to do so [6].In addition to the EDF scheduling criteria it utilizes residual power. Now as PEDF is serving more than one user in the same time slot, this will introduce some interference among the users. If packet to serve belongs to a user not served in this timeslot, the interference will be similar to normal interference scenario in CDMA network. Again if a packet going to be served belongs to a user already served in this time slot will not cause any interference to the original packet and this is true as they belong to same owner.

2.3 HOLPRO

HOLPRO (Head of Line PsuedopRObability) has modified the previous scheduling schemes EDF and PEDF studied in [6]. It uses same notion of PEDF for serving more than one user at a time but utilize a different serving criterion than PEDF and it outperforms PEDF. During each time slot, the head of each packet is assigned a pseudo-probability *(p_i),* which is function of deadline and waiting time of the packet and it is normalized by their packet length *(l_i).* The user with the maximum normalized pseudo-probability (p_i/ l_i) is served first and if there is power remaining in the system, the procedure is repeated with next maximum normalized quantity, as long as the power source remains available [7].The expression for p_i is given bellow:

$$p_i = \frac{\frac{1}{(t_i - w_i)^3}}{\sum_{k=1}^{N} \frac{1}{(t_k - w_k)^3}}$$

So the scheduling criterion is:

$$j = \arg\max(p_i / l_i)$$

Where N= total number of packets in queue

l_i = *packet size*

2.4 PDSTTF

PDSTTF and its modified version M-PDSTTF are the improved versions of EDF, PEDF and HOLPRO. Earlier algorithms like EDF utilize only the delay bound and HOLPRO utilize the delay bound and job size information. PDSTTF utilizes a third condition, the rate information or the channel condition including the delay bound and job size information. Due to the practical limitation of rates set (discrete rates set) and residual power, it has been modified as M- PDSTTF [10]. The scheduling criteria for it is given below

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$$j = \arg\min \left[\frac{(t_i - w_i - \frac{l_i}{R_{i,\max}})l_i}{R_{i,\max}} \right]$$

l_i= *packet size*

$R_{i,\max}$ =the maximum rate the base station (scheduler) can provide to the packet.

3. Modeling for Simulation

For the simulation, candidate algorithms are EDF and PEDF. Modeling for the simulation has been simplified and it is as bellow:

- **Traffic Modeling**

For the simulation purpose, this study is considering the bursty traffic. Bursty traffic will be modeled as an *On-Off* source as in [6].On-Off durations are exponentially distributed. During the *On period*, packets arrive according to a Poisson process and inter-arrival time is exponentially distributed. The packet size is also exponential. For the simulation, considered parameters are:

- Mean On & Off periods are .2 and 1 second respectively
- Within the On period we have consider packet arrival rate 20 packets/s.
- Mean packet size 10000bits.

- **System Modeling**

For the system we have consider a multi cell service area consisting the cell of interest and two tiers of interfering cells. Total transmission power is constant in time and it is 24 watts. There are N numbers of user in the system and they could generate bursty or CBR (constant bit rate) or mixed traffic but in our case, we are considering bursty traffic only.

- **Mathematical Modeling**

Mathematical modeling is helpful for the simulation. Using the models [6] we could write the following relation for the power *Pj,i* , that the mobile i receives from the *j-th* cell:

$$P_{j,i} = P_T (\frac{d_{j,i}}{d_0})^{-4} 10^{0.1\sigma\gamma} \qquad (1)$$

This equation (1) is to calculate the path loss.

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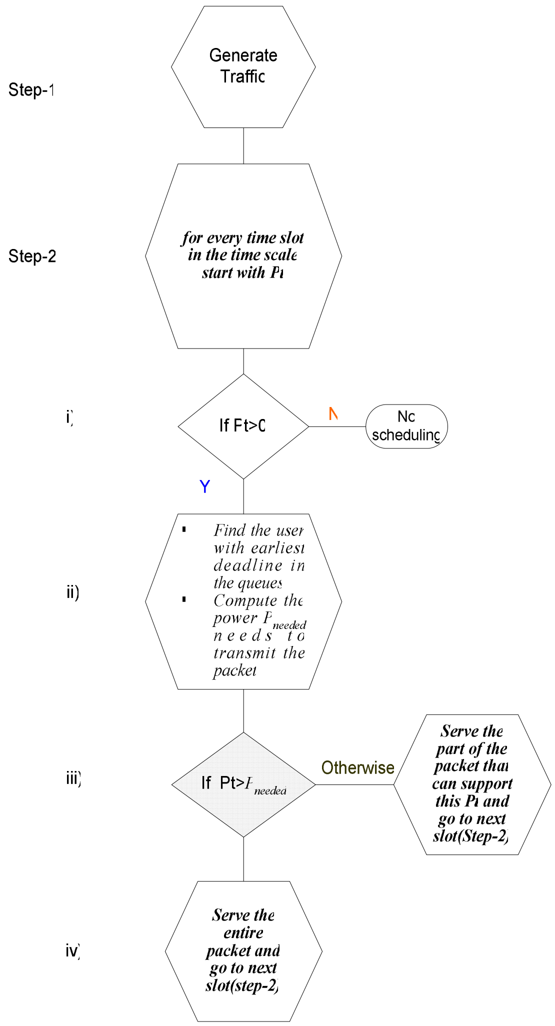

Figure 1: Flow Chart of EDF

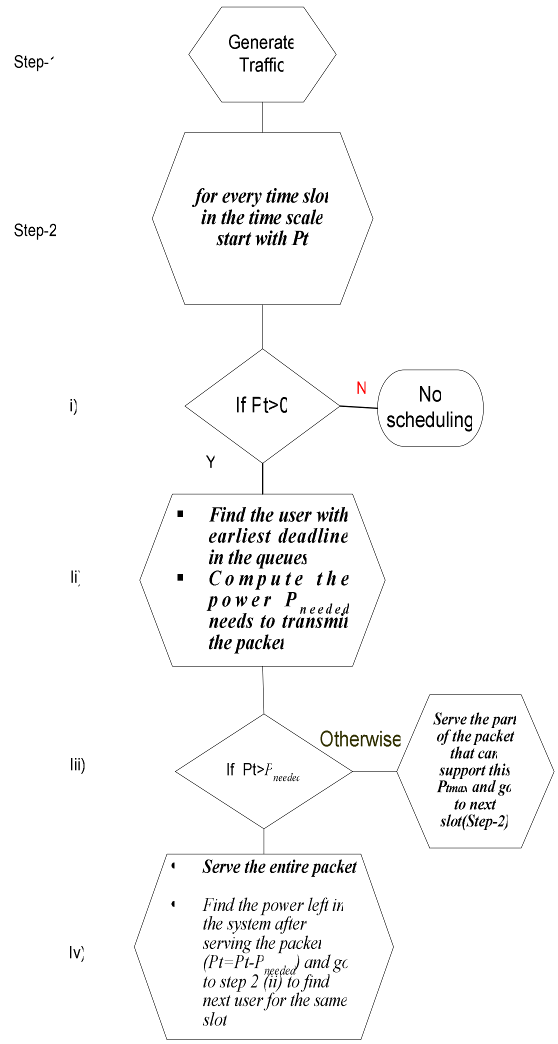

Figure 2: Flow Chart of PEDF

For the needed power calculation, we have used the following equation:

$$P_{needed} = \quad Pi = \frac{E_g(1-\rho+f_d)\beta P_t}{(1-E_g f_d)} \qquad (2)$$

Where:

P_i = fraction of the traffic power for i-th user= P_{needed}

E_g = EbNo/G

G = Bandwidth/Rate=B.W/R_i

R_i = the required data rate=R_{needed}

f_d = sum of the interferences to the i_{th} user from outside cells / sum of the interferences to the i_{th} user from the users of the concerned cell= $\dfrac{\sum_{j=1}^{18} P_{ji}}{\sum_{j\neq i}^{N} P_{0j}}$

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β= fraction of the downlink power used as overhead
ρ = orthogonality loss factor
EbNo = required bit energy to noise ratio

4. Results and Discussion

In our single cell model, we have chosen the following parameters with respective values: *β= .2, ρ =.1, Eb/No = 5db and the system bandwidth B=5Mhz (same as cdma 2000).*We have tested the algorithms for various delays and scheduling intervals. This testing has given a good notion about the impact of *delay threshold* and *scheduling intervals* in the performance of scheduling algorithm. For the results, we have selected four parameters: *Probability* of *Success, Throughput*, Average Used Power and *Probability of failure* and all of these plotted against number of users.

Figure 3 shows the comparative study between EDF and PEDF for bursty traffic. It is clear from the plot that for every performance parameters PEDF is showing better performance. For example: for *Probability of Success 0.*8 EDF can support approximately 12 users and PEDF 45. Again for *Average Power used* PEDF is using the all the power and the EDF only using approximately 3.2 watts and on average it is misusing (19.2-3.2=16 watts) 16 watts. This is because PEDF can support more than one user in each timeslot, if power source permits. So from this result it is clear that PEDF is performing better than EDF as it is utilizing more information (the residual power) than EDF.

Now if we look at the results in figures 4(a) and 4(b) for various *scheduling intervals* then it is very clear that for both the algorithms success rate and throughput increase as the scheduling interval decreases. This is because decreasing the scheduling intervals means increasing the frequency of scheduling. So more users can be scheduled before their deadlines and thereby increased the success rate. The impact of scheduling interval on Average Power used in EDF is remarkable and in PEDF it is very less. If we look at the figures 4(a) and 4(b) it shows that the impact of scheduling interval in EDF is much more than PEDF. This is true, because for the residual power allocation in PEDF more users can pass their deadlines but in EDF can not and only by increasing the scheduling rate or frequency (reducing the scheduling interval) it can be done for EDF. Figure 3 shows the impact of delay threshold on different performance parameters for both the algorithms. Although there is a little improvement for 500 ms than 100ms but more delay threshold can improve performances more.

It is clear from the table1that HOLPRO is better performing than EDF and PEDF in case of all class of traffic and this is because in addition to PEDF criteria, HOLPRO is utilizing the packet size to schedule the users. Looking at the scheduling criteria of HOLPRO it can be said that it is giving priority to smaller packet, which can partly decrease the average packet delay. This is one of the reasons it is better performing than EDF and PEDF [7].

A comparative study between the modified versions of PDSTTF, EDF and HOLPRO can be found in [10].Here modification is done through the addition of residual power allocation model for all the algorithms. It shows that Performance difference between these three algorithms is not significant when traffic load is less than 10packets/sec but in case higher

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load M-PDSTTF performs better than the other two. For example: for a load of 15 packets/sec the packet loss probabilities are:

- .06 for M-PDSTTF
- .095 for M-HOLPRO
- .125 for M-EDF

This is because it can predict whether a packet can finish the transmission within its deadline before the assignment of the power. This can do so as it is utilizing the variable channel conditions whereas other two are not using it.

So from the above analyses and discussion it can be said that utilization of more information about user or user's request for scheduling, the better chance of getting a improved performing scheduling algorithm. In other way it can be said that more gathered information about user's request can help to utilize the resources more efficiently and also provide QoS.This ultimately means EDF, PEDF like online algorithms are reaching more close to an optimal (offline) algorithm. But all of these growing performances are coming at the cost of growing complexity in the scheduler.

Table : A summarized comparative study

	EDF	**PEDF**	**HOLPRO**
Utilizing Conditions:	Delay bound.	Delay bound and the residual power allocation	Delay bound , the packet size and the residual power allocation
Scheme of Scheduling:	$j = \arg\min(t_i - w_i)$ where t_i =delay bound or deadline w_i= waiting time	$j = \arg\min(t_i - w_i)$	$p_i = \frac{\frac{1}{(t_i - w_i)^3}}{\sum_{k=1}^{N} \frac{1}{(t_k - w_k)^3}}$ $j = \arg\max(p_i / l_i)$ where N= total no. of pkts in queue l_i = packet size
Performance Issues(Users Supported): Considering more than 90% of users will satisfy their QoS requirements	EDF can support: • 1 user with CBR only • 24 with bursty and • 1 with mixed traffic	PEDF can support: • 64 users for CBR traffic • 24 users only bursty and • 16 with mixed	HOLPRO can support: • 72 users for CBR • 40 for bursty and • 32 for mixed traffic

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5. Conclusion

Efficient Scheduling algorithms are necessary to utilize limited resources efficiently and to provide QoS. Due to reality online scheduling algorithms are the only solution for this. This paper studied online scheduling algorithms for the downlink of CDMA data networks. Analyses and simulation results show that more gathered information about the user or user's request during the scheduling could make the online scheduling algorithm close to optimum one. Moreover, important observation from the simulation results that the selection of the *scheduling interval* and delay threshold is very important for optimal scheduling algorithm.

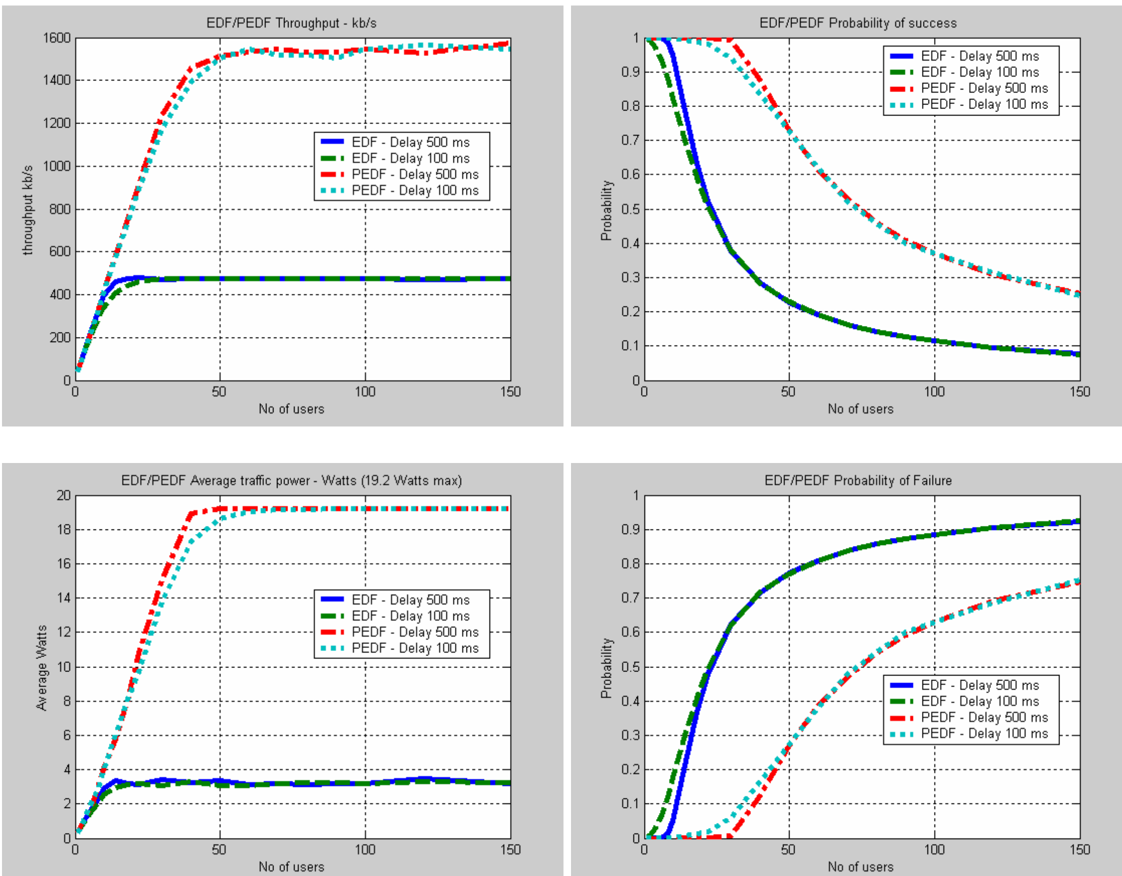

Figure 3: EDF vs. PEDF

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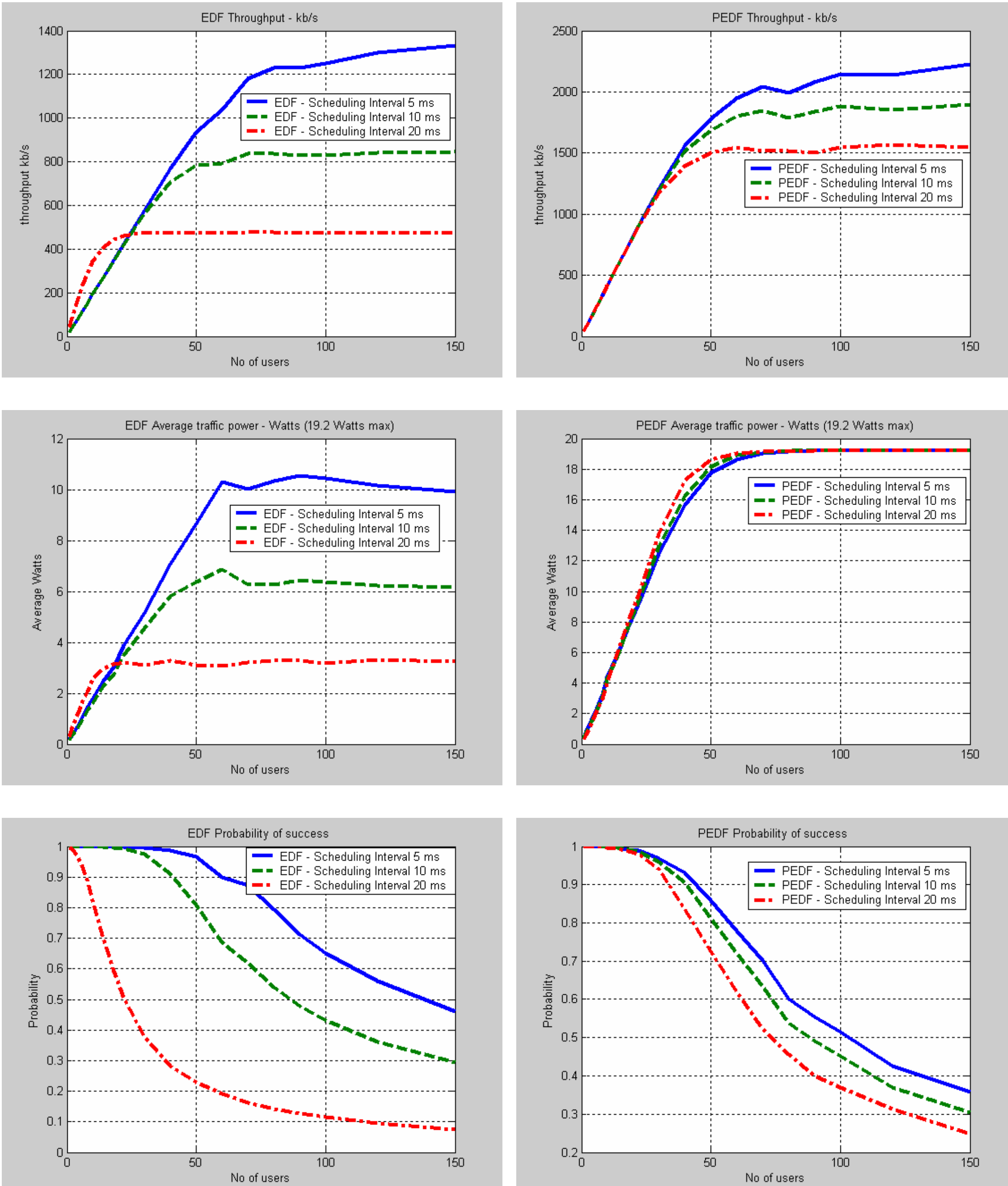

(a) **(b)**

Figure 4: (a) Impact of Scheduling Interval on EDF
(b) Impact of Scheduling Interval on PEDF

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