An Efficient Greedy Approach for Online Patients to Doctors Assignment in a Telemedicine System

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Summary

Telemedicine is a doctor-assistance system which helps to provide healthcare services to patients residing in remote and underprivileged areas. A usual predominant issue associated with this field is the scarcity of trained doctors to serve a large number of patients. In this paper, we take a step to address the scarcity of trained doctors. We proposed and evaluated an algorithm to optimally utilize available doctors in a telemedicine system which minimizes overall waiting time of patients. We used three important parameters of doctors including consultation time, switching time, and workload to develop a scheduling algorithm named Minimum Wait Optimal Load (MWOL) which efficiently utilizes available doctors and minimizes average patients waiting time. We performed discrete event simulations to evaluate our proposed algorithm and compared it with a Round Robin (a strategy that assigns next available doctor to a patient) algorithm with varying consultation and switching time of doctors. Our proposed algorithm MWOL showed increase in its efficiency as compare to Round Robin algorithm from 0.0% to 37.34% and serves more patients in majority of our simulations. We believe that the proposed scheduling algorithm would contribute in telemedicine systems to minimize average patient waiting time and maximize optimal utilization of available doctors thus providing improvement in quality and stability at system level.

Key words:

Patient Scheduling, Telemedicine System, Doctor Utilization, Consultation Time, Switching Time.

1. Introduction

Telemedicine is an emerging technology to facilitate the provision of healthcare services based on Information and Communication Technologies (ICT) to serve a large population living in remote and underprivileged areas [1-7]. Telemedicine systems are capable of providing general, specialized and, emergency services to patients residing in remote areas [1]. The demand of healthcare service is increasing day by day and makes it a challenging task to meet the demand with limited trained healthcare resources specifically doctors. Therefore, telemedicine system has a potential to help overcoming this global challenge. In a typical telemedicine system, patients interact with a telemedicine server using Internet connection from distant location by providing personal information, symptoms, and lab test reports. Once a patient's information reaches to the telemedicine server, an automated process assigns a doctor to the patient. Then the doctor provides the feedback (i.e., evaluations, prescription, etc.) to the patient using smart phone or personal computer. Fig. 1 shows an overall working process of a telemedicine system. A typical telemedicine health-care system consists of three main entities: healthcare consumers (patients), healthcare service providers (doctors, nurses, paramedic staff, etc.), and ICT resources (communication network and telemedicine server). A traditional telemedicine server provides end-user interface (to patients and doctors), storage space for Electronic Health Records (EHR) [7]. It automatically assigns patents to doctors, provide tools to analyze patients' EHR, lab reports, and can even support call center [8].

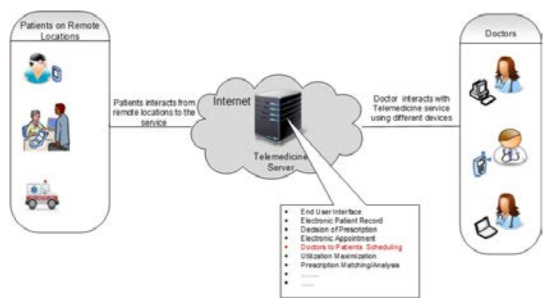

Fig. 1 Overall working process of a telemedicine system

World Health Statistics (WHS) 2013 report [9] indicates a poor doctor to patient ratio for a population of 10,000 for different countries. The report shows Austria and Russian Federation has the highest number of physicians, 48.6 and 43.1 Respectively. On the contrary, Bhutan and Afghanistan have the lowest number of physicians, 0.7 and 1.9, respectively. The increasing shortfall of doctors has several effects including increase in medical cost,

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overcrowded hospitals and clinics, and increase in wait time of patients [10]. Therefore, telemedicine system would be helpful to overcome the global poor ratio of doctors to patient by allowing patients globally to access the healthcare services [11]. However, serving a large number of patients with a minimal average wait time will remain challenging. Current research trends in telemedicine systems are focusing to provide an easy to use and reliable system for increasing healthcare access. However, serving a large number of patients with minimal average wait time of patients; either number of doctors in a telemedicine system should be significantly increased or devise new methods to efficiently assign doctors to patients. It is difficult and time consuming to increase number of doctors; however, developing new methods/algorithms to efficiently assign doctors to patients in a telemedicine system is a viable solution.

In this paper, we propose and evaluate an efficient algorithm named Minimum Wait Optimal Workload (MWOL) to assign patients to doctors which minimizes average waiting time of patients by optimally assigning the available doctors. Our proposed algorithm adopts a greedy approach to assign patients to doctors who are available to serve the patients. Therefore, it helps in overcoming hindrance of patients caused by long waiting time. This would ultimately provide commitment to serve more patients at the earliest possible time slot providing improvement in health services, system level stability, and increase reliability of telemedicine services. We evaluate our proposed algorithm using a set of various discrete event simulations and compare it with a Round Robin scheduling algorithm. In majority of simulations, our proposed algorithm shows better efficiency and serves greater number of patients comparing to Round Robin algorithm.

In the rest of this paper, we explain related work, our proposed algorithm (MWOL) methodology, MWOL scheduling policy, experimental setup, evaluation, and conclusion.

2. Related Work

There has been a great deal of research in developing EHR and Telemedicine services. Yilmaz [12] provides strategies to develop a rule based intelligent health system to store and share EHRs among physicians belonging to different institutes to provide assistance in decision-making for diagnoses. Another important development in EHR research is to reduce patient’s waiting time by allowing patients to get electronic appointments (e-appointments). Chen et al. [13] advocate benefits of e-appointments and suggest that e-appointments help to improve quality of healthcare systems and decrease patient waiting time. Ensuring EHR data security is an important concern, therefore, Almulhem et al. [14] and Păun et al. [15] have designed security models to overcome the possible attacks on EHR systems specifically considering secure electronic storage, life time availability, and unauthorized access based on EN-13606 standards. To maintain and achieve Quality of Service (QoS) in EHR, a study is presented in [16] based on perception and requirement of the users. Wang [17] developed a system named Liflines2 to perform temporal analysis of EHRs to generalize results for a large number of records and to visualize the information that can help doctors in fulfilling complex tasks. Other research trends in the field of EHR includes development and identification of modules to develop EHR to replace conventional paper based system [18], monitoring the health information technology progress [19], physician time impact on quality of healthcare service [20], patient access to information stored in EHR, implementation of ambulatory services to attain proficient contacts between patients and doctors [21, 22], and identification of influential factors of physicians to incorporate usage of EHR [23].

Telemedicine research trends are mainly focusing on cost, quality, accessibility to care, network provisioning, integration of clinical and health services, satisfaction achieved using telemedicine, adoption of technological advancement, and security issues. In [24] authors analyze the security and privacy threats and possible measures that can be taken to overcome the fear of people to adopt telemedicine regarding their safety while using Wireless Sensor Networks (WSN) and Wireless Body Area Networks (WBAN). To overcome the issues of readily availability of network and minimizing processing load on WBAN, [25] proposes a cloud based approach, partition the cloud into a local and global cloud to minimize congestion, interference and delays in data delivery for non-hospitalized remote patients. Convenient and effortless concept of telemedicine based ambient ambulatory services is provided in [26] using Quasi-zenith [27] satellite links. In [28-36] authors studied physicians’ acceptance of telemedicine as a technology and trust of doctors and patients with the system. These papers concluded that patients and doctors are ready to accept telemedicine and it is capable enough to compete with conventional face-to- face healthcare services. Furthermore, telemedicine research community is actively pursuing research related to integration of clinical and health care services (telecardiology, telerehabiliation, teleopthamology, telepsychiatry, teleradiology, etc.), patient education, remote patient monitoring, and adoption of latest ICT technologies including Long Term Evolution (LTE), WiMax, WiFi, Internet of Things (IoT), and Vehicular Adhoc Networks (Vanets).

In healthcare industry, there is a great concern to minimize patient’s waiting time in face to face traditional

healthcare services. For example, the problem of patient's waiting time due to heavily overloaded doctors is identified in [21]. This patient's suffering in wait contributes in degradation of quality of health services. Therefore, many traditional healthcare service providers are adopting appointment scheduling procedures specifically for operation procedures to utilize operation rooms efficiently [37], [38]. For example, in [39] authors propose a scheduling method to utilize an operation room (OR) effectively to minimize waiting time of patients, overtime of doctors and idle time of the OR staff to curtail the incurred cost. In [40] authors identified three areas for attracting and retaining benefaction of new patients. These areas include patient admissions, patient routing, and scheduling of available resources in healthcare facility. In [41] authors proposed an appointment scheduling model based on patient's preferred timing, appointment cancelation and no show behavior. The scheduling procedure is efficient to maximize per day profit by dynamically scheduling patients. All of these appointments and patient scheduling studies include uniform patient arrival, even distribution of demands, uniform service time, arrival punctuality, equal intermediate intervals of patients with a primary focus on conventional face to face health systems mostly for surgical (operation room) scheduling.
However, there is no study that mentioned patient scheduling procedure in a telemedicine system to minimize patient's waiting time and efficient utilization of doctors. In this paper, we take first step to propose and evaluate an efficient algorithm to assign doctors to patients automatically that minimizes patient waiting time comparing to a baseline approach. The proposed scheduling procedure considers dynamic arrival of patients, early assignment of priority patients, non-uniform service time, early and late arrival of patients, and interruptions/breaks of physicians.

3. Methodology

In this section, we explain our methodology to efficiently schedule doctors to patients in a telemedicine system. Our proposed scheduling process is designed to minimize an overall average patient wait time, increase patient satisfaction in the telemedicine system, and effectively utilize available doctors. First, we explain important parameters associated with doctors, and then provide a mathematical formulation for doctors to patient assignment, and then we explain the proposed MWOL scheduling algorithm, and finally we explain the Round Robin scheduling algorithm used as a baseline to compare with the proposed algorithm.

3.1 Selected Parameters

We associate average consultation time, average switching time (some literature refer this as an idle time), workload (maximum number of patients that a doctor can serve at a given time interval), and availability with each doctor registered in the telemedicine system [42]. The proposed scheduling algorithm uses these parameters to minimize the average patient wait time. These parameters are selected to cover most of the qualitative parameters of the healthcare domain. We explain these parameters briefly in the following subsections.

3.1.1 Consultation Time

Consultation time is an end to end time required by a doctor to serve a patient. In a telemedicine system, consultation time includes reviewing patient's history, investigating current disease information, examining patient reports, and writing prescription for the patient.

3.1.2 Switching Time

Switching time refers to a time required by a doctor to shift from one patient to another. In telemedicine system, switching time includes network latency involved to download patient's information. Moreover, switching time may also include a time doctor may take to rest to eliminate stress factor and overcome the frustration caused by excessive load.

3.1.3 Workload

Workload refers to a maximum number of patients that a doctor may serve in a given time period [42]. In our proposed model, two different queues (a data structure that works on first in first out mechanism) namely wait queue and job queue are associated with each doctor. Wait queue contains patients that are assigned to the doctor and waiting for their turn to be served. Job queue contains a patient which is currently under consultation of the doctor.

3.1.4. Doctor's Availability

Each doctor is associated with a binary variable named availability to indicate current state of a doctor in the telemedicine system. If a doctor is logged in to the telemedicine system then his/her availability is set to 1 otherwise default value remains 0.

3.2 Mathematical Formulation

Our proposed scheduling algorithm is designed to minimize patients wait time and improves satisfaction of patients towards the telemedicine service. Therefore, our objective function is to minimize average patient wait time through efficient scheduling of patients to doctor.

Table 1 explains the symbol we used in the rest of this paper.

Table 1: List of Symbols

Symbols	*Explanation*
$D = \{D_1, D_2, D_3, \dots, D_m\}$	Set of doctors in the system
D_j	Dj represents jth doctor in the system
$P = \{P_1, P_2, P_3, \dots, P_n\}$	Set of patients in the system
P_i	Pi represents ith patient in the system
W_{P_i}	Average total time (wait time and serving time) of the Patient Pi in the system
$C = \{C_{D_1}, C_{D_2}, C_{D_3}, \dots, C_{D_m}\}$	Set of average consultation time of doctors (D).
C_{D_j}	C_{D_j} represents jth doctor's consultation time
$Q = \{Q_{D_1}, Q_{D_2}, Q_{D_3}, \dots, Q_{D_m}\}$	Set of waiting queue of doctors (D).
Q_{D_j}	Q_{D_j} represents jth doctor's' waiting queue.
$S = \{S_{D_1}, S_{D_2}, S_{D_3}, \dots, S_{D_m}\}$	Set of switching time of doctors (D).
S_{D_j}	S_{D_j} represents jth doctor's switching time.

The objective function is explained in (1):

$$minimize \sum_{i=1}^{n} W_{P_i} \quad (1)$$

Where WPi is the average patient wait time in the Telemedicine system, calculated using (2):

$$W_{P_i} = \min_{j=1\dots m} \left(\left(C_{D_j} + S_{D_j} \right) * \left(Size\left(Q_{D_j} \right) + 1 \right) \right) \quad (2)$$

Equation (1), the objective function, in conjunction with (2) ensures to minimize the average patient wait time in an online telemedicine system using a greedy approach. The proposed greedy approach always selects the doctor with minimum switching and consultation time to assign the doctor which leads to an optimal allocation to minimize wait time of patients.

Algorithm I: MWOL Algorithm

```
For each patient Pi in the system  If
    (Pi == priority patient)
        Assign Pi to head of Pre-Scheduling Queue  Else
        Assign Pi to tail of Pre-Scheduling Queue
While (pre-scheduling queue has a patient)
        Pi is a patient extracted from the pre-scheduling queue
        CalculateW_Pi using Equation2
Assign Pi to doctor's Dj (that gives minimum W_Pi) wait  queue
```

Fig. 2 shows placement of pre-scheduling queue and assignment of patients to doctor's wait and job queue.

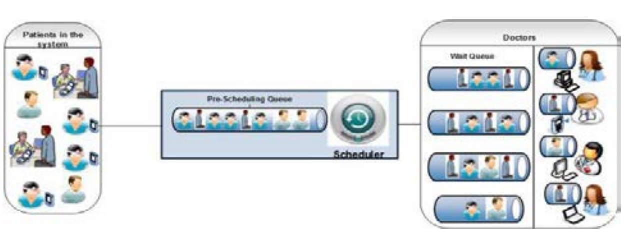

Fig. 2 Queuing and Scheduling process of the MWOL Algorithm

It is possible that the proposed scheduling algorithm may identify a set of doctors (more than one) providing same minimum wait time for a specific patient. For this special case, the scheduler identifies a doctor having minimum patients in his/her wait queue and the sum of switching and consultation time is also minimum among the set of doctors.

We use generic round robin algorithm (Explained in Algorithm 2) as a baseline to compare with our proposed MWOL algorithm.

Algorithm2: Round Robin Algorithm

```
For each patient Pi in the system
If (Pi == priority patient)
    Assign Pi to head of Pre-Scheduling Queue
Else
    Assign Pi to tail of Pre-Scheduling Queue
While (pre-scheduling queue has a patient)
    Pi is a patient extracted from the pre-scheduling queue
    j (jth Number of Doctors) = i% whereas 'i' is the patient
index
Assign Pi to doctors'sDj Wait queue
```

3.3 Simulation Design

We used Matlab's Simulink toolbox to perform discrete time event simulation to evaluate our proposed algorithm. To initialize the input parameters (consultation time and switching time for doctors), we performed a survey with a sample size of 110 doctors. Participants of the survey were consultants, teaching faculty, clinicians, dentists, physicians, surgeons, medical officers, training medical officers, and house officers. In our proposed simulation based experimental setup, patients are generated using poison distribution which caters non uniform and non-punctual arrival of the patients. The variation in consultation time and switching time in conjunction with non-uniform patient arrival indicates the inclusion of un-even demand distribution of doctors and patients and non-uniform service time as well. Moreover, the variation in switching time provides un-equal intermediate intervals of patients. Consequently, it overcomes most of the weaknesses found in the parameters of previous literature. To understand different scenarios, we performed four simulations with varying switching time and consultation time of doctors. Simulation scenarios also consider different doctor to patient ratios varying from 1:5, 1:25, and 1:50. All different variations of important parameters of the simulations are summarized in Table 2.

Table 2: Summary of Simulation Parameters

	Switching Time		**Consultation Time**		Doctor Patient Ration	Wait Queue Size
	Min	Max	Min	Max		
Simulation 1	10.96	10.96	12.15	12.15	1:5	7
					1:25	30
					1:50	60
Simulation 2	1.75	8.057	5.25	14.25	1:5	7
					1:25	30
					1:50	60

Simulation 3	1.75	15	5.17	18.5	1:5	7
					1:25	30
					1:50	60
Simulation 4	1.429	25	5.25	20.50	1:5	7
					1:25	30
					1:50	60

To evaluate the simulation results of the proposed algorithm and Round Robin, we measure average patient wait time, percentile average difference (PAD), and number of patients served during each simulation. The PAD formula is explained in the equation 3.

$$\text{PAD} = \left\{ \frac{(\text{Avg PWT of MWOL} - \text{Avg PWT of RR})}{\left(\frac{\text{Avg PWT of MWOL} + \text{Avg PWT of RR}}{2}\right)} \right\} * 100 \quad (3)$$

Where in the above equation, PWT refers to Patient Wait Time, RR refers to Round Robin, and MWOL is a name of our proposed algorithm.

4. Results

In this section, we explain the results obtained through simulations using our proposed and baseline Round Robin algorithms. We explain each simulation results in following sub sections:

4.1 Simulation 1

In this simulation all doctors' consultation and switching time are initialized with same values. We observed that both the algorithms, Round Robin and MWOL, provides identical patient's average wait time and patients served for all variations of doctor to patient ratios. Therefore, PAD is 0% for all patients to doctor ration. Performance of both the algorithms is similar due to homogeneity in the doctor's switching and consultation time. The average increase in patient wait time is depicted in Fig. 3 for the three cases of 1:5, b) 1:25 and c) 1:50 of doctor to patient ratio respectively. As the behavior of both the algorithms is same therefore, Round Robin Algorithm overlaps the MWOL algorithm.

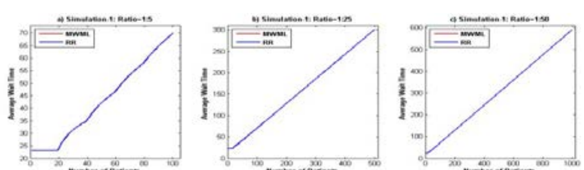

Fig 3 Average Wait Time of Simulation 1 (Worst Case), for doctor to patient Ratio of a) 1:5, b) 1:25 and c) 1:50

4.2 Simulation 2

In this simulation, we assigned varying consultation and switching time to the doctors. However the difference among doctor's consultation and switching is minimum and increasing uniformly. The value of switching time varies from 1.75 to 8.057 minutes and consultation time varies from 5.25 to 14.25 minutes. Our proposed algorithm MWOL performs slightly better by providing less average patient wait time comparing to Round Robin. We observe PAD 10.53%, 11.46% and 10.92% for doctor to patient ratio of 1:5, 1:25, and 1:50 respectively. However, a slightly greater number of patients are served using MWOL algorithm comparing to Round Robin. The average increase in patient wait time is depicted in fig. 4 for the three cases a) 1:5, b) 1:25 and c) 1:50 of doctor to patient ratio respectively. The PAD ratio has been decreased slightly with a maximum of 0.54% upon the scheduling of arrival of greater number patients to the system indicating the incorporation of frustration experienced due increase in workload.

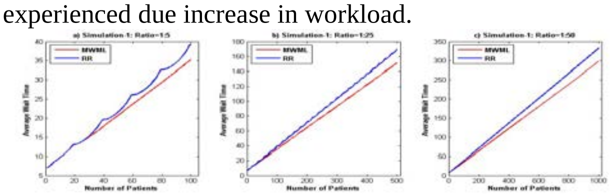

Fig. 4 Average Wait Time of Simulation 2 (Below Average Case), for doctor to patient Ratio of a) 1:5, b) 1:25 and c) 1:50

4.3 Simulation 3

In this simulation, we assigned consultation and switching time with moderate difference and increasing uniformly. The values of switching time are varying from 1.75 to 15 minutes and consultation times are varying from 5.17 to 18.5 minutes for the doctors available in telemedicine system (table 2). MWOL algorithm outperforms Round Robin in average patient wait time. We observe PAD 18.38%, 19.40%, and 16.72% for doctor to patient ratio of 1:5, 1:25, and 1:50 respectively. The number of patients served using MWOL algorithm is observed higher when compared to Round Robin algorithm (table 3).The average increase in patient wait time is depicted in fig. 5 for the three cases of a) 1:5, b) 1:25 and c) 1:50 of doctor to patient ratio respectively. The PAD ratio has been decreased slightly with a maximum of 2.68% upon the scheduling of arrival of greater number patients to the system indicating the incorporation of frustration experienced due increase in workload.

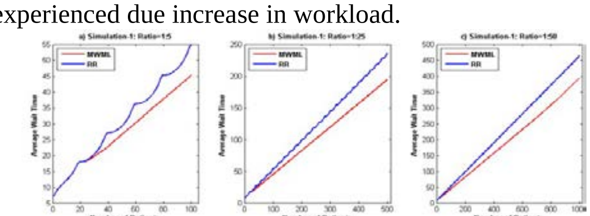

Fig 5 Average Wait Time of Simulation 3 (Average Case), for doctor to patient Ratio of a) 1:5, b) 1:25 and c) 1:50

4.4 Simulation 4:

In this simulation, we assigned consultation and switching time to doctors with a large difference increasing uniformly. The values of switching time are varying from 1.429 to 25 minutes and consultation times are varying from 5.25 to
20.50 minutes for the doctors available in telemedicine system (table 2). We observe PAD 36.36%, 37.34%, and 29.98% for doctor to patient ratio of 1:5, 1:25, and 1:50 respectively (table 3). The number of patients served using MWOL algorithm is substantially higher comparing to Round Robin algorithm. The average increase in patient wait time is depicted in fig. 6 for the three cases of a) 1:5, b) 1:25 and c) 1:50 of doctor to patient ratio respectively. The PAD ratio has been decreased slightly with a maximum of 7.36% upon the scheduling of arrival of greater number patients to the system indicating the incorporation of frustration experienced due increase in workload.

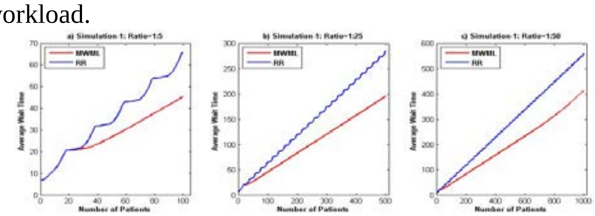

Fig 6 Average Wait Time of Simulation 3 (Best Case), for doctor to patient Ratio of a) 1:5, b) 1:25 and c) 1:50

We summarized simulation results in Table 3. For each simulation, the table shows total number of patients, number of available doctors, average wait time in minutes, PAD, and percentage of patients served by the scheduling algorithms.

Table 3: Summary of the Results

	No. of Patient	***No. of Doctor***	***Algorithm***	***Average Wait (Min.)***	***PAD***	***Patient Served***
Simulation 1	100	20	RR	70.02	0%	68.0%
			MWML	70.02		67.0%
	500	20	RR	301.03	0%	82.6%
			MWML	301.03		82.6%
	1000	20	RR	589.89	0%	84.7%
			MWML	589.89		84.6%
Simulation 2	100	20	RR	39.19	10.53%	88.0%
			MWML	35.27		90.0%
	500	20	RR	169.74	11.46%	96.0%
			MWML	151.35		96.6%
	1000	20	RR	332.94	10.92%	98.2
			MWML	298.44		98.8
Simulation 3	100	20	RR	54.39	18.38%	78.0%
			MWML	45.23		88.0%
	500	20	RR	236.14	19.4%	88.0%
			MWML	194.37		95.2%
	1000	20	RR	463.30	16.72%	89.9%
			MWML	391.83		98.2%
Simulation 4	100	20	RR	65.57	36.36%	72.0%
			MWML	45.37		88.0%
	500	20	RR	284.85	37.34%	79.6%
			MWML	195.21		95.6%
	1000	20	RR	558.97	29.98%	81.6%
			MWML	413.24		92.6%

5. Conclusion

In this paper we proposed and evaluated an efficient algorithm named MWOL (Minimum Wait and Optimal Load) to assign doctors to patients in a telemedicine system based on a greedy approach. The proposed algorithm considers doctor's average switching and consultation time to schedule the patient to minimize the patient's wait time by utilizing doctors efficiently. We compared our proposed algorithm with a Round Robin algorithm (a strategy to assign next available doctor to the patient) using different simulations. The simulations are designed to evaluate the effect of consultation and switching time of doctors in overall minimizing average patient wait time. Our simulations results show that the MWOL outperforms Round Robin when consultation and switching time of doctors are varying. However, MWOL gives comparable performance while consultation and switching time of doctors are constant. In reality, it is difficult that all the doctors take same switching and patient handling time, therefore, the proposed algorithm would help to increase the number of patients served, reduce the overall average patient wait time to get the prescriptions and feedback from doctors using online telemedicine system to achieve quality and system level stability. In countries where patient to doctor ratio is poor, telemedicine is an effective technology to introduce and ensure the availability of healthcare to every individuals. However, limited number of trained telemedicine doctors need to be utilized efficiently to increase quick assistance of healthcare to remote and underprivileged areas. Therefore, our proposed algorithm will help to minimize average patient wait time in a telemedicine system by utilizing available doctors efficiently. Currently, we are extending the proposed algorithm to allow scheduling of medical specialist using patient specific parameters.

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