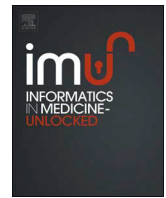




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Performance prediction of interactive telemedicine

S. Sasikala^{*}, K. Indhira, V.M. Chandrasekaran

School of Advanced Sciences, Vellore Institute of Technology, Vellore 632014, India

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ABSTRACT

Telemedicine is a remote medical practice, which utilizes information and communication technology to provide healthcare and exchange of health information for distance places. Diagnosis and prescription for rural and remote area patients are the main advantages of this system. The major categories of telemedicine are store-and-forward, remote patient monitoring and interactive telemedicine. Interactive telemedicine is a real-time interaction between patients and doctors. This method can be conducted in a nursing home or at the patient's house via a video-conferencing system. Moreover, this is more convenient for patients, than to obtain health care with a caretaker in person. However, Internet-based networks are congested with many users. We considered interactive telemedicine as a queueing system and analyzed it by using the method of supplementary variables. We obtained the performance measures through a probability generating function. The numerical results of the queueing system may be useful to provide service satisfactorily and update the utility function of interactive telemedicine.

1. Introduction

In medical systems, patients have to go to a hospital or clinic for consultation and treatment; therefore, it is inconvenient for patients, and for patients residing in rural and remote areas [1]. Telemedicine is a remote medical practice, which utilizes advanced telecommunications and information technologies for the delivery of healthcare and the exchange of health information across distances [2,3]. Health care organizations showing interest in the implementation of telemedicine technology to develop the health care facilities [4–6]. It bridges the gap between patients from rural areas and medical professionals located in city centers. The main advantages of telemedicine are specialist care, reducing long travels and increasing health care quality in rural and remote areas [7–9]. It is a natural growth of healthcare in the digital world and a convenient way to access because of internet-based communication applications [10–12].

The major categories of telemedicine are remote patient monitoring, store-and-forward and interactive method [13]. In remote patient monitoring, patients are monitored through the use of advanced technologies like a smart watch and medical devices [14,15]. Store and forward method helps in sharing of medical information from one location to another location [16,17]. Interactive telemedicine is a real-time interaction between patients and doctors separated by distance [18–20].

Performance measures of queueing systems using supplementary variable technique can be found in Ref. [21]. Queueing systems with

repeated trial have been successfully used to model many practical problems in telecommunication networks, packet switching networks, collision avoidance and computer systems etc. [22–24]. New customers arrive from outside the system to get service. If they find the server is busy at the time of their arrival is obliged to leave the service area and repeat the demand after some random time. Between trials, unsatisfied customers may join the pool of unsatisfied customers called a retrial group or may not join in retrial group [25,26].

In some queueing situation, all arriving customers need first essential service but some of them only need second optional service. As soon as first essential service is completed, the customer may opt for second optional service or may leave from service area [27–30]. Once the queue gets cleared the server may leave for a secondary job. On completion of a secondary job, if the queue is empty, then the server may wait for the new customer to arrive or leaves for another secondary job [31–33]. One of the important thing in the practical situation is perfectly reliable servers do not exist and it may breakdown while serving the customers [34–36]. The customer just being served before breakdown waits for the remaining service to complete [37]. The failed server will immediately send to a repair facility. In repair station, there is a chance to start repair after some period of time due to some reasons [38–40].

According to our knowledge, less number of works carried out for performance measures in telemedicine. Priya et al. [41] have derived the performance measures for medical E-commerce shopping cart abandonment in the cloud by $M^X/G/1$ queueing model with reneging through

^{*} Corresponding author.

E-mail addresses: sasikala.settu@vit.ac.in (S. Sasikala), indhira@vit.ac.in (K. Indhira), vmcsn@vit.ac.in (V.M. Chandrasekaran).

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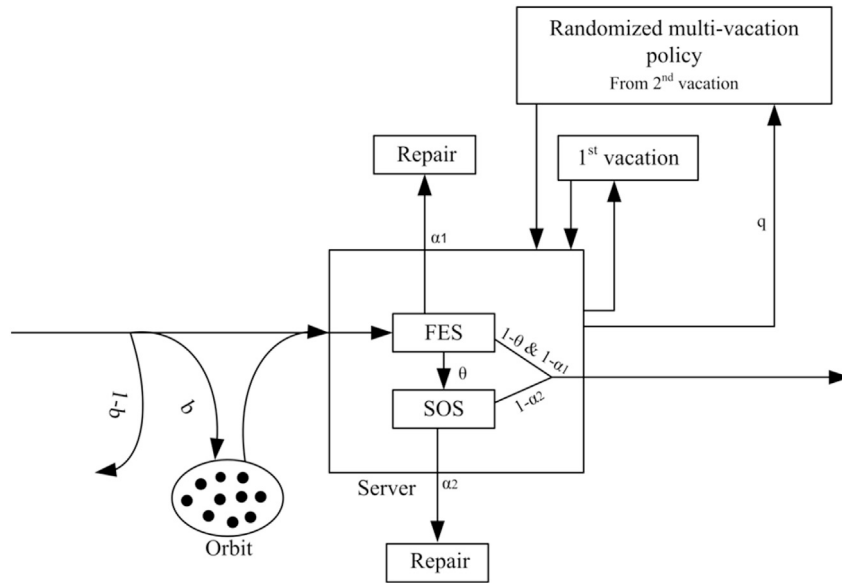


Fig. 1. Schematic representation of the proposed model.

probability generating functions. Similarly, we considered interactive telemedicine as batch arrival retrial queueing system with two phases of service, balking, delaying repair and randomized multi-vacation policy. The objective of this study is to obtain the performance measures of interactive telemedicine through probability generating function by the method of supplementary variables.

This paper structured as follows: First, we have given a detailed description of telemedicine. Second, we developed the differential-difference equations for interactive telemedicine. Third, we have derived the system performance measures. Finally, some numerical examples are presented for the proposed model.

2. Model description

Patients are arriving in batches to get a consultation by the interactive method. If the doctor is available while trying for consultation, patients will get consultation immediately. If the doctor is not available or busy, the patients may retry for service after some random time. Once the interactive session got over, patients have the option for treatment. The system may fail for short interval of time and immediately will send to a repair facility. If the orbit length is empty at a service completion instant, the server will move to a secondary job. If the orbit length is empty at the end of a vacation, the server either remains idle with probability p or leaves for another vacation with probability q ($= 1 - p$). When one or more patients arrive during server idle, the server immediately starts providing service for the patients. The various stochastic processes are involved in this system and can be modeled as $M^X/G/1$ retrial queueing system with balking, delaying repair and randomized multi-secondary job. Schematic representation of the proposed model is given in Fig. 1.

Telemedicine has been well-defined with the following assumptions.

- 2.1 Patients are arriving in groups of size k according to compound Poisson process with the rate λ . Let be X_k the size of the k^{th} arrival batch and $X(z)$ be its probability generating function.
- 2.2 If the server is free at the time of patients arrival, the arriving patients begins to be served one by one according to the order of their arrival. Otherwise, if the server is busy, breakdown or on vacation, the patients may become a source of repeated patients with probability b or may leave with probability $1 - b$. The source of repeated patients viewed as a sort of queue. Consecutive retrial times form a sequence of independent random variables having

continuous distribution function $\{O(x)\}$ with the first-order differential equation $\delta(x)dx = \frac{dO(x)}{1-O(x)}, \forall x \geq 0$.

- 2.3 Telemedicine centers provide heterogeneous service in two phases. First one is video conferencing (First Essential Service) and the other is a treatment (Second Optional Service). First essential service is common for all patients and the other is patients choice. Successive service times form a sequence of independent random variables having continuous distribution function $\{S_i(x)\}$ with the first-order differential equation $\mu_i(x)dx = \frac{dS_i(x)}{1-S_i(x)}, \forall x \geq 0$.
- 2.4 If the orbit size is empty at service completion instant, the server will move for a secondary job. After a vacation, if the orbit is empty, the server may opt for one more vacation with probability q . Consecutive secondary jobs having continuous distribution function $\{V(x)\}$ with the first-order differential equation $w(x)dx = \frac{dV(x)}{1-V(x)}, \forall x \geq 0$.
- 2.5 The server may breakdown for short interval of time in both phases with respective probabilities α_1 and α_2 .
- 2.6 The failed system immediately will send to repair facility and sometimes repair may start after some period of time due to some reasons. Successive delay times form a sequence of independent random variables having continuous distribution function $\{D_i(y)\}$ with the first-order differential equation $\eta_i(y)dy = \frac{dD_i(y)}{1-D_i(y)}, \forall y \geq 0$.
- 2.7 The successive repair times of breakdown server form a sequence of independent random variables having continuous distribution function $\{R_i(y)\}$ with the first-order differential equation $\gamma_i(y)dy = \frac{dR_i(y)}{1-R_i(y)}, \forall y \geq 0$.
- 2.8 Patients leave the service area once service completed successfully.

3. Mathematical formulation

The following steady state differential-difference equations are obtained by using the supplementary variable technique

$$\lambda I_0 = p \int_0^\infty \sum_{n=0}^\infty \pi_{j,0}(x) w(x) dx \quad (1)$$

$$\frac{dI_n(x)}{dx} = -(\lambda + \delta(x)) I_n(x), \quad x > 0, \quad n \geq 1 \quad (2)$$

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